A PRACTICAL TREATISE

ON

MECHANICAL ENGINEERING,

COMPRISING

METALLURGY, MOULDING, CASTING, FORGING, TOOLS, WORKSHOP MACHINERY, MECHANICAL MANIPULATION, MANUFACTURE OF THE STEAM-ENGINE, ETC. ETC.

ILLUSTRATED WITH

TWENTY-EIGHT PLATES OF BOILERS, STEAM-ENGINES, WORKSHOP MACHINERY, ETC.

And Ninety-One Wood Engravings:

WITH

AN APPENDIX

ON THE ANALYSIS OF IRON AND IRON ORES.

BY

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Dedication.

TO

THOMAS WICKSTEED, Esq.,

MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,
HONORARY MEMBER OF THE ROYAL POLYTECHNIC SOCIETY OF CORNWALL,
ETC. ETC.

THIS WORK

Is Respectfully Dedicated,

IN GRATEFUL ACKNOWLEDGMENT OF NUMEROUS KINDNESSES RECEIVED
FROM HIM
BY HIS OBEDIENT SERVANT,

THE AUTHOR.

PREFACE.

THE peculiar character of the volume now submitted to the scientific world, imperatively demands a full account of the views which have led the author to adopt the system of arrangement pursued in the following pages.

The great number of works hitherto published on the various branches of mechanical engineering may generally be classed under two heads—viz., elementary works, describing the general principles and forms of steam-engines, and complete treatises, including detailed descriptions, scientific disquisitions, and rules for calculating the proportions of various machines; the latter class also occasionally touching upon manufactures. There appeared, however, to be a very obvious chasm in the literature of mechanical engineering, some treatise being required possessing the following qualifications.

Practical method, portability, conciseness, and the exclusion of all unnecessary matter; the subject-matter comprising all the general operations connected with mechanical engineering, the scientific principles and examples illustrating the present condition of mechanical engineering. In the hope, therefore, of supplying to practical engineers and to students such a work the present treatise has been written.

The account of the processes which constitute the manufacture of iron commences with an introduction setting forth the natural condition of the minerals from which the metals of commerce are derived, and enumerating the operations conducted in the factory.

In the first chapter, the metallurgy of iron, copper, lead, tin,

and zinc is considered; the nature and localities of the various metalliferous ores being described, and also the practical methods most usually employed for the reduction of the metals to the conditions in which they occur in commerce; the apparatus required, and the principles upon which their action depends, and the mode of working them being also included.

Then follows a description of the various processes of forging and of the instruments used by the smith. After which the construction of patterns, the methods of forming moulds of various kinds, and of casting metals are discussed.

The form and action of the cutting tools of the engineer have been carefully detailed, a thorough knowledge of the requirements which must be satisfied, in order to secure their correct action, being most important, though a proper appreciation of the forms of the principal machine tools is scarcely less necessary; wherefore some sound examples of turning-lathes, shaping, slotting, drilling, planing, and other machines have been illustrated and described. As a sequel to the foregoing descriptions, an account of workshop manipulation is given, so far as it admits of description.

The physical basis of the steam-engine is next considered, the more refined methods of analysis being avoided, so as to retain a strictly practical character. Dr. Joule's equivalent for the calculation of the amount of work to be obtained from a given quantity of heat is inserted, forming as it does a convenient means for the *expression* of quantities of heat. But it is derived from experiments upon the amount of heat generated by friction of liquids; and, therefore, the author does not feel justified in considering its application to thermo-motive engines demonstrated, the facts extant being insufficient for this purpose. Stimer's and Isherwood's experiments on the practical utility of using steam expansively have also been discussed at some length.

In the chapter on the Principles of Mechanical Construction, an attempt has been made so to generalize the theory of the action of levers, hydrostatic presses, &c., as to replace by a simple calculation, easily remembered and applied, the numerous rules and formulæ which have hitherto been so abundantly supplied for levers, divided into various orders, and for other machinery, and

which, being generally given without any notice of the reasoning upon which they are based, cannot be remembered, and frequently serve but to confuse the reader. The laws of falling bodies of rotatory motion, &c., are also explained.

The general forms of steam-engines, and principles of steam-boilers, and qualifications of various kinds of engines are briefly treated, followed by lengthy accounts of the form and manufacture of each principal element of the steam-engine, after which the form, action, and manufacture of various kinds of pumps and valves are treated.

Practical formulæ for the length of boilers, descriptions of various kinds of boilers, and of the modes of constructing them, also accounts of the paddle-wheel, screw, and hydraulic propellers, with miscellaneous remarks upon some of the applications of steam power, have also received due attention; and particular stress is laid upon the necessity of having reliable experiments upon steam-engines, and attention is drawn to the inferiority of modern engines in point of economy. It is indeed a fact much to be regretted, that notwithstanding the researches of scientific men, and the labours of practical engineers, no improvements have been made in the economy of the steam-engine since 1845. The remainder of the work is occupied by descriptions of examples of pumping, rotative, marine, locomotive, traction, and steam fire-engines, concluding with a Glossary of the technical terms used throughout the work.

As in the account of the metallurgy of iron notice has been taken of the effects of various foreign ingredients with which the iron of commerce is always more or less contaminated, it has been thought advisable to add an Appendix containing the various methods of analysing chemically the various ores of iron and specimens of iron, so as to enable those who may feel disposed to examine for themselves such samples as may come under their notice.

The examples of machinery illustrated have been carefully selected, and every means taken to secure correctness of the Plates.

The thanks of the Author are due to many scientific gentlemen who have assisted him with plans and information; especially to Thomas Wicksteed, Esq., for the plans of the large pumping-

engine at the Grand Junction Water-works, designed by him in 1845; the Bolton and Watt pumping-engine at the East London Water-works, erected in 1829; Cornish boiler now erecting at the Scarborough Water-works; also for valuable information concerning the above, and the new pumping engine now erecting at the Scarborough Water-works. To C. G. Gumpel, Esq., for plans of his hydraulic propeller, information concerning the same, and experiments performed for the Author's information upon the same. Also to Messrs. Pullan and Lake for plans of their new patent agricultural locomotive, and for information respecting the same and their new traction engine.

WESTMINSTER,
January, 1863.

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A PRACTICAL TREATISE

ON

MECHANICAL ENGINEERING.

INTRODUCTION.

In the following pages we purpose to treat of the various processes and manipulations which the materials employed in the construction of steam-engines and other machinery must undergo before the complete machine can be produced. We think it desirable, before proceeding with a practical description of these processes and manipulations, to give a brief account of the order in which they occur, and of the ends which they are intended to fulfil, to enable us subsequently to treat each branch of the iron manufacture without touching upon collateral operations.

Iron, in common with the other metals generally used for mechanical purposes, does not occur pure in nature, but is invariably combined with other substances, from some or all of which it must be freed before it is fit for the purposes of commerce. In order to remove these foreign ingredients from the ores or minerals in which the various metals occur, sundry chemical and mechanical processes are required. In the first instance, it is necessary to remove the excess of argillaceous matrix with which many ores are contaminated. Some are subsequently roasted, to expel moisture, &c.; after which the ores may be smelted, in order to obtain in a state of greater or less purity—according to circumstances, the metals contained in them. This process of smelting is of a chemical character, and consists principally, in the case of iron, in depriving the metallic oxide of its oxygen, which is effected by means of carbon at a high tempe-

rature, which has a greater affinity for that element than has the ferruginous material. In the case, however, of ores consisting of metallic sulphides, a somewhat different course is requisite, as will be hereafter explained.

After smelting, iron is usually obtained as cast-iron, which, when bar-iron is required, must undergo some further purification. We may here pause to explain the physical and chemical distinctions existing between cast and wrought-iron. Cast-iron contains many impurities, consisting principally of silicon, manganese, carbon, sulphur, phosphorus, aluminium, and sometimes traces of copper, arsenic, and other foreign metals. Most of these elements may be removed by oxidation in the form of slag, and in the removal of the impurities chiefly consists the conversion of cast-iron into wrought-iron; and the process may be conducted by exposing a large surface of the heated metal to the oxidising influence of the atmospheric air.

Another material which we must here mention is steel. This consists of nearly pure iron, combined with a small portion of carbon, and perhaps of nitrogen also. The subject of the action of nitrogen in the production of acieration, as the conversion of iron into steel is termed, is a point upon which there has recently been much discussion, and some very interesting experiments by MM. Caron and Fremy. The latter has found that by exposing pure iron at a high temperature to the action of ammonia, nitrogen is thereby absorbed, which enables the metal subsequently to take up a portion of carbon from certain carburetted gases. This effect, however, is not well accounted for, as it is not by any means proved that cyanogen is formed during the operation; we must therefore, for the present, content ourselves with the fact that steel is thus produced, waiting for further experiment to explain the theory of its production.

It is not to be expected that a quantity of foreign elements will exist alloyed or combined with a metal, without producing a very marked change in its physical properties; and thus we find that cast-iron is very widely different in its nature from wrought-iron. Cast-iron is granular, brittle, rigid, elastic, and offers but little resistance to tensile force, although it well withstands compression; whereas, on the other hand, wrought-iron is fibrous, tough, flexible, offers great resistance to tensile force, but not so

much to compressive force. These are the general characteristics of the two materials; but various specimens of them exhibit different degrees of strength, according to their composition. Phosphorus, sulphur, and silicon appear to be highly injurious; whereas titanium, nickel, and perhaps manganese, exert a contrary action. Steel, besides possessing in a high degree the qualities of wrought-iron, when in a soft state, admits also of being raised to various degrees of hardness. The processes of hardening and tempering are very simple, and are thus conducted. The steel to be hardened, having been raised to a red heat, is plunged into water, or other cooling medium, whereby a very great state of hardness is obtained. The fracture is then crystalline. Steel in this condition is unfit for the generality of purposes, and therefore requires to be tempered previous to use; to effect this it is gradually heated, becoming the softer the higher the temperature to which it is raised; the proper point of temper is ascertained by the colour exhibited by a film of oxide, which forms on the exterior of the metal. This colour is probably produced by the interference of light, which is caused by a ray of light striking the upper surface of the film, a part of it being immediately reflected, whilst another portion passes through the film with refraction, and is reflected from its lower surface, when, if the film be thin, it frequently happens that some of the component rays reflected from the lower surface interfere with and neutralize some of those previously reflected from the upper surface. Steel works for various purposes are thus with certainty prepared with the proper temper: for coach-springs and similar articles, it is tempered to a blue tint; for small springs, such as the spiral and blade springs made in the smaller machinery, the metal is raised to such a heat as will impart to it a pale blue tint; for cutting tools, the colour is straw-yellow, varying in shade according to the manner in which the tool is to be used.

We must now offer a few remarks upon the other materials with which, subsequently, we shall have to deal. Copper, as used in commerce, is prepared in a state of comparative purity; but the processes required for its reduction are exceedingly complicated, five or six operations in reverberatory furnaces being necessary for the reduction of sulphide of copper. The metal is ductile, but requires when being worked to be frequently annealed; it

may be wrought under the hammer cold, but works better at a slight elevation of temperature. It has been found that the addition of a small quantity of phosphorus materially improves the strength of copper; for although this element is so detrimental to iron, yet when it is combined with copper in the proportion of two to four per cent., it imparts to that metal considerable hardness and tenacity; its tensile resistance then becoming about four-fifths of that of ordinary iron, or two-thirds of that of the Low Moor iron plates. Alloys of copper with aluminium have the advantage of homogeneity and tenacity, but from the fact that aluminium is powerfully affected by alkaline substances, its use is for many purposes precluded. Copper, when combined with about four per cent. of silicon, possesses the hardness of steel and the tenacity of wrought-iron, and if this alloy could be manufactured on a large scale with convenience, it would doubtless be found applicable to a great variety of purposes. It may be interesting here to mention the method of combining the phosphorus and copper, as advised by F. A. Abel, Esq., Director of the Chemical Establishment of the War Department. The phosphorus should be coated with copper by immersing the pieces in a solution of sulphate of copper; after which process they may be handled with perfect safety, and when they are thrown into the molten metal, the external film of copper will efficiently protect them from oxidation during the very short period required for combination. One of the most important alloys of copper is brass, though gun-metal is perhaps almost as extensive in its applications. The strength, however, of brass is not by any means equal to that of the phosphorus and copper alloy.

The metals, tin, lead, and zinc, will also demand some consideration, but it is unnecessary here to comment farther upon them.

Having concluded our introductory remarks upon the earlier processes of metallurgy, we may proceed to mention the branch of manufacture of which we purpose next to treat. This includes the forging of metal both by hand and by steam-power; and also the various methods of reducing the materials to the required size and form. In this section we shall also refer to the formation of wood-patterns, as the models from which castings are usually made are called. In this part we shall most par-

ticularly explain the construction and method of using the tools and machinery with which the workmen must be provided, in order accurately to execute the manipulations with which they are engaged.

Our next subject will comprise the theory or principles upon which the construction of the steam-engine generally is based, as also that of other machinery; but we shall not seek here to enter into very elaborate arguments or demonstrations, but rather to explain in the simplest and most succinct manner well-established facts, with which it is important for every practical man to be acquainted. We shall also include in this section simple rules for proportioning the various parts of machinery.

The remainder of the work will be occupied with descriptions of the various forms of steam-engines usually applied to manufacturing, marine, and locomotive purposes.

We will now conclude these brief introductory remarks, which may be regarded as an account of the branches of manipulative science which we purpose discussing, and proceed with the detailed consideration of the same.

CHAPTER I.

ON METALLURGY.

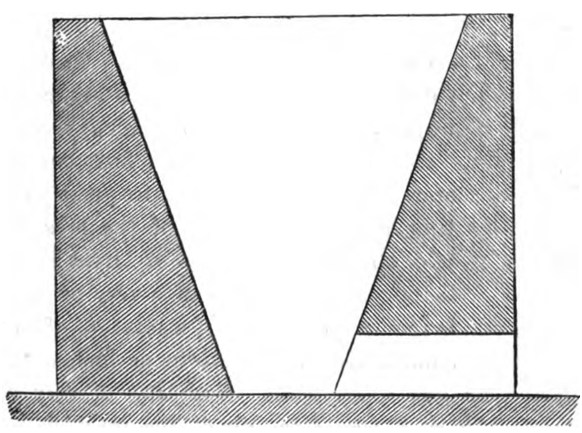
Before proceeding with a description of the processes employed in the metallurgy of iron, it is necessary to enumerate the minerals from which it is usually obtained. Those which contain at least twenty per cent. of metal are usually considered ores, but if they contain less they are regarded as fluxes, the use of which in metallurgical operations will subsequently be indicated. Ores of iron are very widely disseminated, being found as beds in the sedimentary rocks, or as veins and massive deposits in the older formations, in which position the most valuable ores are obtained. They frequently occur beneath the coal-measures, which arrangement is exceedingly convenient, the fuel for the manufacture being found on the same spot with the ferruginous minerals. In some of the North American States, and in other places, magnetic iron-sand occurs in the drift at the foot of mountain ranges, and bog-iron ores are also occasionally found in a similar position. In the cretaceous system large deposits of ferruginous sand occur, but on account of their low yield they have never been extensively worked. Below the cretaceous system there are some extensive deposits of iron, which were formerly worked in Hampshire and Sussex, the metals being reduced by charcoal supplied from the neighbouring forests; these are, however, at the present day neglected. In Northamptonshire and the Cleveland district of North Yorkshire are found beds of oolitic iron ore, sometimes of a thickness of twenty feet, and affording in many instances thirty-three per cent. of metal. A few thin beds occurring in the lias formation have been partly worked in Lincolnshire and Yorkshire, but they are not rich in metal; in this formation, magnetic iron-sand and small portions of hematite also occur. The iron-works of this country, however, are supplied principally from the earthy carbonates of the coal-

measures, from which excellent metal is obtained. The coal-fields of South Wales, Staffordshire, Yorkshire, Scotland, North Wales, Shropshire, and Warwickshire, contain abundant deposits of this ore.

When the iron ores have been raised to the surface, the first operation consists in the cleansing of them. The earthy carbonates of the coal formations are placed in heaps, and left for several months, after which it will be found that the excess of adhering clay shale has become separated by the action of the atmosphere, leaving the ores clean and fit for the furnace. The oolitic ores and the magnetic oxides and rich hematites of foreign countries are frequently cleansed by making use of the superior specific gravity of the ferruginous portion of the products, but in England the hematites undergo no other preparation than a partial hand-picking to separate large masses of refuse matter. We may now explain the theory of the reduction of iron. If an oxide of iron be highly heated in contact with carbon, the latter, having a greater affinity than the former for oxygen, takes it from the ferruginous oxide, thereby eliminating the metal. It is, however, necessary to provide some substance readily fusible, in order to dissolve certain impurities; such substances are called fluxes. They should be incapable of holding in solution any considerable quantity of iron. Chalk forms an excellent flux, but limestone is the cheapest material, and therefore most frequently employed. It may be interesting here to insert a list of the ores, fuels, and fluxes used in some of the principal works of Great Britain. At the Whitehaven foundry, hematite ore of a very pure character is employed, and is reduced by means of a mixture of Newcastle coke and coke manufactured at the works as fuel, with Whitehaven limestone and black shale, consisting of clay and carbonaceous matter, as fluxes. A sample of this ore when dried contained sixty-nine per cent. of metallic iron, generally pure, containing a large amount of silicon. At the South Bank furnaces an earthy carbonate of iron with silicate is used containing thirty-five per cent. of metal, with a hard variety of coke as fuel, and dark grey limestone for flux. At the Butterley works, blue rake and brown rake ores are used, the latter containing about thirty per cent. of metal; Brand's hard coal is the fuel, and Bullbridge or Crowford limestone the flux. At Lay's iron-works, a

mixture of various ores is employed; the fuel is a mixture of Durham and Derbyshire Thickbone cokes, with Froghall and Dudley limestone as flux. At the Heyford iron-works, ochrey brown ironstone, containing about thirty-nine per cent. of metal, is reduced by coke prepared from the coal of the South Yorkshire Railway Company, fluxed with limestone consisting of an agglomeration of fossil shells. The Ystalyfera iron is produced from clay, ironstone, and hematite, the fuel being anthracite coal, and the flux a light-coloured limestone. These remarks are extracted from the recent Report on Cast-iron, ordered by the House of Commons to be printed, on July 30th, 1858. We may now pass on to describe the ordinary process of smelting. For the reduction of iron a blast furnace is used of the form shown in Plate I.; but previous to smelting the ore it is sometimes necessary to calcine it, which is effected in a kiln of the form shown at Fig. 1. The kiln in which the ore is calcined is usually built in

Fig. 1.



the rear of the blast furnace, the general form being that of the inverted frustrum of a cone; the diameter at top is usually about eight or nine feet, and the height fourteen or fifteen feet, with a bottom width of two feet. At the bottom of the kiln is an aperture through which the calcined ore may be withdrawn, and also a number of apertures for the admission of air; above the kiln runs a railroad, along which loaded waggons pass, and deliver the contents into the kiln. The general arrangements are best seen from the section above referred to.

When about to operate with a new kiln, the following course is usually pursued: a fire is lighted on the floor, and as soon as full ignition is obtained other fuel is added, with alternate strata of ore, until the kiln is filled, care being taken to work the kiln so that these strata descend uniformly, being exposed to a higher temperature at the upper part of the kiln, where active combustion is maintained; the temperature diminishing as the ore passes towards the aperture, through which it is subsequently withdrawn. If the operation of calcining be continuous, which is most advantageous, the kiln requires to be filled regularly and continuously over its entire area, as irregularity or negligence in conducting the process of calcination will result in loss of economy. It is also necessary that the ore should be broken into pieces of uniform size. In some districts the ore is calcined in the open air, but this method of procedure is far from satisfactory. The perfect calcination results in the expulsion of its volatile constituents, such as water, carbonic acid, sulphur, and organic matter. By this process, also, any protoxide of iron which may exist in the ore is converted into peroxide.

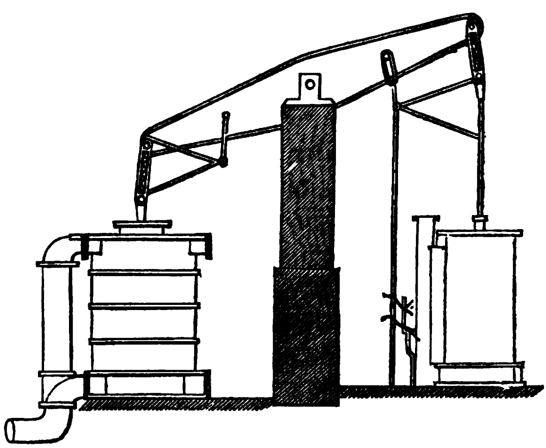
Generally it is considered advisable to calcine ores of the same formation together; but if any particular sample should contain much sulphur, it is desirable to treat it by itself, in order to avoid contaminating cleaner samples. The expulsion of sulphur, when it exists in considerable quantity, is facilitated by the introduction of a jet of steam with atmospheric air, whereby the sulphur passes off in combination with hydrogen, the metal remaining oxidized.

The calcination being completed, the ores are ready to be subjected to the action of the blast furnace. A section of one of these structures is shown on Plate I.; it consists of two truncated cones, joined at their widest extremities; the bottom of the furnace is called the hearth, and the lower part of the lower cone the boshes, and is constructed of fire brick, or of a very refractory material called fire stone. This part of the furnace is subjected to a very intense heat, and it is therefore necessary to construct it of such material as may be sufficiently durable. To prevent the occurrence of a sharp angle where the two cones are joined, either a curve or a narrow cylindrical belt is inserted, whereby the edges are rounded off, and a space formed which is called the belly. The upper cone or body of the furnace is formed by an

interior lining of fire bricks, which is again enveloped in a casing made up of broken scoriæ or refractory sand, whereby the internal lining or shirt of the furnace is separated from the external coating of fire bricks, which is supported by a mass of masonry composed of stone and common stock bricks. The opening at the top of the furnace is called the throat or tunnel hole, and is surmounted by a chimney, in which there are openings through which the ore, fuel, and flux are supplied to the furnace. Air is supplied to the furnace by tuyeres or "tue irons," as they are sometimes called, consisting of nozzles, through which the blast is forced. In practice it is found advantageous to build the furnaces at the bottom of a declivity, so that the summits may be connected by a bridge at the neighbouring high ground, in order to facilitate the supply of fuel, &c.; if, however, this cannot be done, they must be raised by an inclined plane, or by a hydraulic lift, or some other convenient means. The dimensions of these furnaces differ widely, according to the nature of the product desired and of the ores operated upon: the height varying from thirty-six to seventy feet, the most common height being about fifty feet; a furnace of this height producing on the average about sixty tons of cast-iron per week.

The blowing machine ordinarily employed for supplying the

FIG. 2.



blast to the furnace is of the form shown Fig. 2. It consists of a large cast-iron cylinder, accurately bored, and provided with an

air-tight piston; the cylinder is closed at both extremities by iron covers, a stuffing-box being attached to the upper cover, through which the piston-rod passes; the whole forming a double-acting pump, driven by a beam-engine.

We will now describe the method of working practically the blast furnace. Let us suppose that the furnace is newly erected. It is first requisite to light it. To prevent the masonry from being exposed to the injurious influence of sudden heat, the lighting is commenced by igniting a quantity of loose fuel in the arch forming the breast of the furnace. After some days, when it is sufficiently heated, fuel is thrown in through the throat, and allowed to rise as far as the middle of the boshes; when the drying is still further advanced, the whole internal cavity is gradually filled up with fuel, after which the blast is gradually and cautiously applied, being subsequently raised to its full pressure. When the fuel is sufficiently sunk, a small charge of the ore and flux is spread over it; after which, alternate layers of fuel, ore, and flux are added. The blowing machine is almost invariably worked by steam power, and upon the average it may be calculated that one horse power is required in the blowing engine for every two and a half tons of metal produced per week. In one of the Welsh smelting works it was found that furnaces producing sixty tons of cast-iron per week consume, on an average, three thousand six hundred cubic feet of air per minute, the power expended being one horse for every two and a tenth tons of metal per week. In the continental furnaces, where charcoal is used, the blast pressure frequently does not exceed half a pound per square inch. For coke, the pressure is from one and a half to three and a half pounds per square inch, the average being about two and a half pounds. The furnaces are sometimes worked with hot blast, and to heat the blast of a furnace producing sixty tons per week to the temperature of 600° Fahrenheit, about thirty-two tons of coals will be consumed weekly, being a little more than one-half the weight of the metal produced. But the blast is also sometimes heated by the combustion of gases drawn off from the upper part of the furnace, before they have become ignited by contact with the atmosphere. Various means of effecting this have been devised, but we shall not here occupy more space with the description of

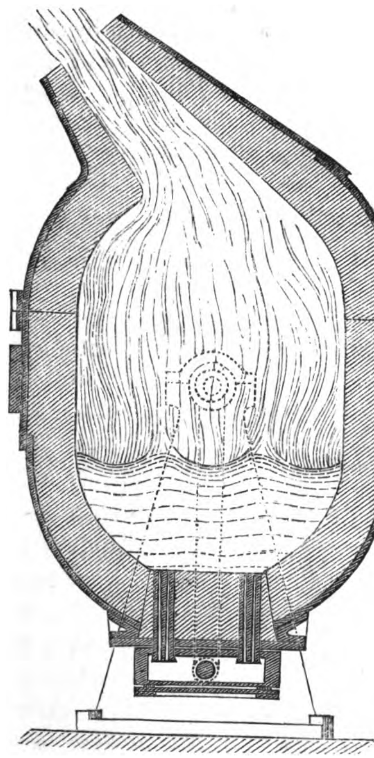
them. The cast-iron produced in the blast furnace is usually run out into troughs formed in sand, from the sides of which smaller troughs branch out. The iron formed in the main troughs is termed "sow," and that in the smaller branches "pig," which latter is supposed to be of better quality. The iron in this condition is ready to be used for castings, or to be converted into wrought-iron. Of the former process we shall treat hereafter: we will now proceed to consider the latter.

There are various methods employed for the refining of iron, but we shall here confine our attention to the English process. The transformation of cast into wrought-iron is effected by means of pit-coal or coke in two consecutive operations; in the first it is heated in a furnace, which is usually built on a mass of brick-work about nine feet square, the sides of the fireplace being formed of hollow cast-iron troughs, through which water is constantly circulating in order to prevent their fusion. The metal is fused in this furnace, and subjected to the action of the blast, whereby a considerable portion of its carbon is oxidized and removed, and also nearly the whole of its silicon. The metal, which is usually covered with blisters, is then run out into flat moulds. A section is shown at Plate II.

The further purification or puddling is conducted in a reverberatory furnace, when the remaining impurities are to a great extent removed by oxidation. The puddling of fine metal from the refinery is thus conducted. The sole, or centre part of the furnace, is charged with broken metal, rich slag, and iron scales; the doors and sides of the furnace are now closed, and fuel thrown on the grate. When the metal begins to melt, the door is opened and the charge continually stirred until it arrives at a pasty state, when the fire is lowered. The metallic bath now appears to boil, from the evolution of carbonic oxide, which burns on its surface with a blue flame. The stirring of the mass is then continued until it becomes sandy, and subsequently of an uniform granular appearance. The iron is now said to work heavily, and a portion of the scoria runs off; after which the iron is formed into balls, heated in the hottest part of the furnace, and the slag expressed under a hammer or squeezer. The charge of a puddling furnace is usually from three and a half to five tons. A section of one form of a reverberatory furnace is shown at Plate III.

We may here mention Mr. Bessemer's process for refining iron. This consists, firstly, in running the fluid iron from the furnace into a closed or nearly closed vessel, after which air is forced through it, thereby affording oxygen sufficient to cause combustion of the iron, and the oxidation of other impurities. A section of the vessel used is shown.—Fig. 3.

FIG. 3.



Mr. Clay has also proposed to refine iron by a process of granulation produced by dropping iron from the top of a lofty tower into a water-tank, in the same manner that lead shot is cast, and it is stated that by this method so large a surface is exposed to the oxidizing influence of the air, that the metal is purified by the oxidation of its foreign ingredients.

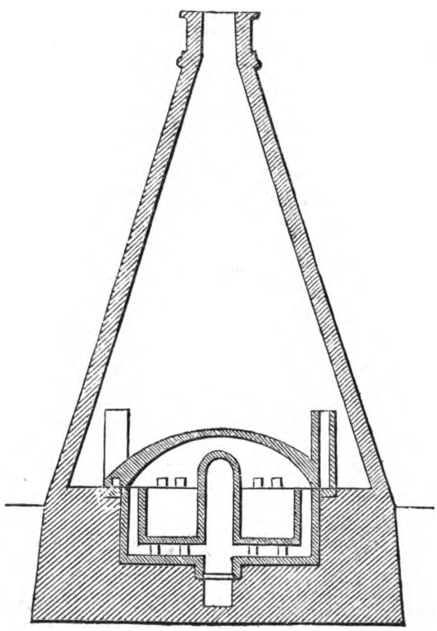
It has also been proposed to oxidize the impurities by allowing the molten metal to fall upon a cone a few feet from the floor,

whereby the crude iron should become finely divided, thereby exposing a considerable surface to the action of the atmosphere.

We have yet to speak of the formation of steel, but on this subject we will be exceedingly brief. The wrought-iron intended to be converted into steel is usually drawn out into bars, which are subsequently packed in powdered charcoal in large cases, and there exposed in a suitable furnace to a bright red heat, until the metal has taken up a sufficient portion of carbon to convert it into steel. Steel may, however, also be formed by subjecting wrought iron at a high temperature to the action of a carburetted gas. A section of the furnace used for this process of cementation is shown at Fig. 4.

We will now turn our attention to the metallurgical operations

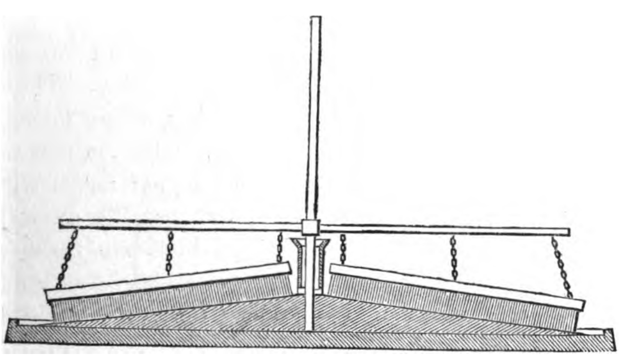
FIG. 4.



required for the manufacture of copper. The ores of copper are principally found in the primary and lower transition rocks. Red oxide of copper is an ore of a bright red colour, specimens of which may be found in Cornwall, Saxony, France, Siberia,

Brazil, and the Lake Superior district. Black oxide of copper occurs in granular masses of velvety black colour; it occurs in small quantities in Cornwall, and more abundantly in France, Siberia, and South Australia; but it is found in the largest quantities in the Lake Superior district. Carbonate of copper is commonly found in reniform, mammillated, or botryoidal masses. It is found in Siberia, South Australia, and Cornwall, and contains about fifty-five per cent. of metallic copper. Sulphuret of copper is the most abundant deposit of copper in the whole world, and of this many species occur; but the most common ore in England is the sulphuret of copper and iron, the extensive copper mines of Cornwall and Devon being principally wrought upon this ore. The first process of which we have to speak is the cleansing of the ores. The ore is first crushed and sifted, and subsequently washed or jigged: which consists in placing the ore in a sieve in a cistern of water, and jerking it up and down. By this means the portions of ore are momentarily suspended in the water, and are presently found to arrange themselves with the largest pieces at the bottom, and the smaller fragments above. The hand process of jigging is, however, applicable only to small pieces of ore; and when larger quantities are to be dealt with, machinery driven by steam or water power is substituted for the

FIG. 5.



hand sieve. The round buddle is also used for cleansing copper ores. This apparatus, of which a section is shown at Fig. 5, consists of a conical bed, on the centre of which a stream of water continually pours, where the ore is also supplied, being uniformly

distributed by means of brushes suspended from arms on a vertical spindle. The specific gravity of the ore on this apparatus determines its position, the richest mineral being deposited at the centre, the deposit diminishing in value towards the outer edge of the buddle, where a broad ring of tailings, or refuse matter, is taken out; the ores thus cleaned are ready for the smelter. The smelting of copper is conducted in reverberatory furnaces, differing slightly in form, the treatment being complicated, the mineral undergoing ten operations. In the first, the ores are roasted or calcined in order to volatilize such substances as sulphur, zinc, arsenic, antimony, &c. The second process consists of fusing the calcined products with other minerals not previously calcined; this is called roasting for coarse metal. In the next operation, the remaining sulphur, which could not be driven off by heat alone, is expelled, it being alternately exposed to the action of an oxidating flame and that of a reducing flame. The fourth process is termed melting for white metal, in which the iron is eliminated as slag by combining it with silica. The fifth operation, melting for blue metal, is very similar to the fourth, the calcined coarse metal being fused with roasted ores rich in copper. The sixth process consists in remelting the slags, to cause the production of a matt, in which the copper in the various slags is brought together. The seventh process, roasting white metal for the production of superior white metal, has a twofold object: the charge being first oxidized to decompose the sulphuret of iron into oxide of iron and sulphurous acid, the latter being evolved, while the former combines with silica, and is carried off as a fusible slag. The whole mass is then melted. The eighth operation, roasting for regulus, is conducted with the following effects:—Oxidation first occurs, but as the fusion proceeds the oxide of copper reacts with the sulphuret; sulphurous acid is evolved, and metallic copper, or a sulphuret of copper, is produced; the products are three, all of which have to be reworked: a regulus containing twenty-one per cent. of copper, a slag containing about ten per cent., and bottoms, or alloys with other metals. The ninth operation comprises the roasting and fusing of regulus for crude metal; and the tenth process consists in the refining and toughening of the same. After fusion, the scoria is raked off the surface of the metal, and a few shovelfulls of powdered anthracite or wood charcoal are

thrown on the surface of the charge, after which it is stirred with a pole of green wood for about twenty minutes, after which it has attained the condition of fine metal. This brief account contains the substance of the ordinary process of copper smelting.

The most common ores of zinc are the carbonate, the sulphuret, and silicate. The ores are first roasted or calcined, and the zinc is subsequently distilled from them in retorts, the forms of which vary in different districts.

The tin of commerce is obtained from the native oxide of that metal, some of the tin ores requiring, however, a careful cleansing previously to the smelting operation. By the first process the reduction is conducted in a reverberatory furnace, the fuel used being common pit-coal, the ores operated upon being mixed with a proper amount of powdered carbonaceous matter. By the second process, the oxide is reduced in a small blast furnace, supplied with air by a blowing machine driven by steam power.

The ores of lead usually treated in this country principally consist of galena, or sulphuret of lead, which, however, before it comes into the hands of the smelter, has been deprived by a careful mechanical preparation of a large portion of the earthy and silicious ingredients with which it was originally associated.

The galena, or sulphuret of lead, is treated in a reverberatory furnace, where it is first subjected to a roasting process, which, by the oxidation of the constituent elements of the mineral, converts it into sulphate of lead and oxide of lead, which, reacting on each other, cause the production of metallic lead, which frequently contains sufficient silver to render its extraction a matter of commercial importance. As, however, the process by which the silver is separated belongs rather to the metallurgy of silver than to that of lead, we shall not here occupy our space with an account of it.

From the foregoing descriptions we find that the reverberatory furnace admits of a greater range of chemical reactions than the blast furnace will allow of, and it may be interesting here briefly to review the chemical operations occurring in the two furnaces.

In the ordinary blast furnace deoxidation of the metalliferous minerals alone takes place, and in the iron furnaces it occurs in the following manner.

The ore and fuel are, as before stated, thrown into the furnace

in regular strata, and descend in the same order to the belly, or upper part of the boshes. The temperature of the upper part, or cone, is not very considerable, but in the neighbourhood of the boshes more heat is evolved, and on the hearth it is developed in its fullest intensity. The air thrown into the hearth there meets with fuel in a high state of incandescence, and from the large excess of oxygen present, a vigorous combustion ensues. The combustion produced by the blast usually extends as far as the middle of the boshes, but its activity is there much reduced, as the greater part of the oxygen has been converted into carbonic acid before the ascending current reaches that point. The carbonic acid then combines with carbon to form carbonic oxide, which subsequently exercises a powerful reducing influence on the oxide of iron.

In the reverberatory furnace an oxidating influence may be obtained by the introduction of atmospheric air to the sole, or laboratory of the furnace, or the metal may be deoxidated in a manner similar to the action of a blast furnace; or it may be merely fused, by adjusting the admission of air so that its oxygen is almost entirely removed before passing the fire bridge.

CHAPTER II.

ON FORGING IRON.

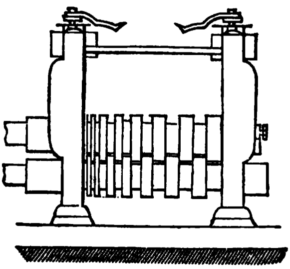
The earliest process of forging which iron undergoes has for its purpose the forming of the blooms or balls of iron into bars or plates, in order that they may subsequently be applied by the mechanical engineer to the various purposes for which they are required. In this operation the blooms are frequently operated upon by hammers raised by a shaft furnished with cams, or projections, which act upon the tail of the hammer; but the most effective apparatus is the steam-hammer, of which various forms have from time to time been produced. We shall, however, here describe a fifty-cwt. steam-hammer on Nasmyth's plan.

An elevation of this steam-hammer, with a section of the foundation, is shown, Plate IV. The apparatus consists of a very strong cast-iron frame, supporting at the top a steam cylinder of the ordinary construction; within this cylinder is a piston, to which is attached a piston-rod, working steam-tight through the bottom cover of the cylinder; at the lower end of this piston-rod is a large mass of metal which constitutes the hammer-head; to the lower surface of this block the hammer-face is fixed by a dovetail joint, firmly wedged up. To the lower part of the steam cylinder the slide valve is attached, being surrounded by a jacket, as shown; it is worked by the action of the hammer-head upon a tappet, placed in front of the guides by which the hammer-head is retained in position during its fall, or by the hand-gear, shown. Beneath the hammer is an anvil, with a hard face dovetailed into it, and wedged up firm; the whole apparatus rests on foundations consisting of piles for the support of the anvil, and of cinders beaten down for the support of the hammer-frame. The action of the hammer is as follows: the steam being admitted beneath the piston, raises it, together with the hammer-head; when a sufficient elevation has been obtained, the

steam is allowed to escape, and the hammer-head falls upon the work to be wrought, the operation being repeated as often as may be desirable. This machine can be worked by those accustomed to its use with great accuracy, very delicate operations having been frequently performed, such as the corking of bottles, cracking of nuts without injuring the kernels, &c.

We may also include among the machinery used in forging iron, the rollers employed to reduce it to the form of bars; for this purpose, stout cylinders, with grooves turned upon them, are employed, the metal being passed through grooves gradually diminishing in size until the metal is reduced to the desired dimensions; the general form of this apparatus is shown in Fig. 6. For rolling-plates true cylinders are required, and very great care

Fig. 6.

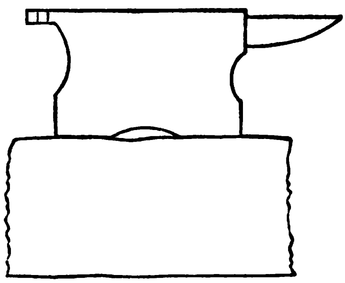


must be employed for the production of thin plates. We may now proceed to describe the smaller machinery of the forge; we must first, however, mention, that it is very important to select coals of a suitable nature as fuel for the forge; the best for the purpose is a strong dense durable coal, possessing a good body, dull and dirty in appearance. Bright easily-broken coal is not good for this purpose, and such matters as tend to combine with the iron in the form of clinkers are very deleterious, sulphur being an element which should especially be avoided in forge-fuel. Tanfield coal when unmixed with other varieties, is very convenient for the smith's work.

The first piece of apparatus of the smaller class which we have to describe is the forge-furnace, which is used when small portions of iron are being worked, larger masses being heated in a reverberatory furnace; these forges may be made eight or nine feet

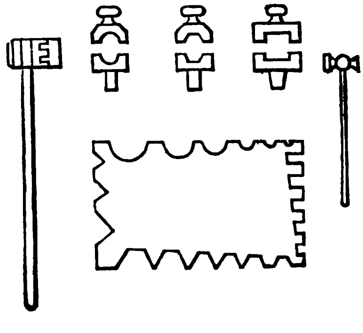
square, and consist of a mass of brick-work as a foundation to support the fire; at the back of the fire is a tue-iron, through which a blast is supplied. This blast is frequently produced by a revolving fan; the whole is surmounted by a hood and chimney, which serve to carry off the smoke and heated air. The iron is worked upon a stout mass of iron, called an anvil (shown Fig. 7).

Fig. 7.



It is rested on a large block of wood, to raise it to a convenient height, and the metal is beaten by means of sledge-hammers and hand-hammers, swages or dies being used when requisite, to produce any particular form. The lower swage is fitted to an aperture in the anvil, the iron to be wrought placed upon it, and the upper swage laid on the iron, and struck with the hammer. The upper swage is held by means of a light hazel rod, which prevents the shock of the hammer from producing any strain upon the hand of the operator. For ordinary forgings, two men are employed: the smith, who is responsible for the work, and receives a high

Fig. 8.



salary, and the hammer-man, or striker, whose duty it is to wield the sledge-hammer, and work the bellows, when such are used for the maintenance of the blast. Some forms of swages, and also a combined bottom swage, or swage-block, are shown at Fig. 8, as also a sledge and a hand-hammer.

For welding iron a flux is required, in order to prevent the oxidation of the surfaces to be joined. For this purpose fine white sand and common salt may be used. The iron is first heated, dipped in the flux, and the heating continued, until the metal has attained a white heat. The flux is then fused over the surface, and has dissolved any oxide of iron which may have formed; the two surfaces to be joined are laid together and struck continuously, working towards the edges, in order to expel the flux and insure a perfect union of the metal. Cast-steel and wrought-iron scarcely admit of being welded together with facility; but shear-steel may thus be joined to wrought-iron; in which case, however, the steel is not raised to nearly so high a temperature as the iron.

For heavy forgings a crane is also required, but the form of this is too well known to require any special description. In large forgings each particular piece of metal requires different treatment, according to the use for which it is destined. Thus the heavy screw shaft, which is subject to torsion only, will require a different arrangement to that employed when a crank or cross-head is formed. The most ancient method of forging shafts consisted in piling together a certain number of slabs of iron, which were subsequently heated, welded, and hammered into the cylindrical form required. When, however, it became necessary to make larger shafts, this method was improved upon: a pile of slabs being taken as before, of which only a portion was drawn out to the circular form, a large mass being left at one extremity, on which to weld more slabs when required: after which the metal could be drawn out a little longer, the operations being continued as long as was needful. This method is still employed at many works in England, Scotland, and America, with considerable success, but it requires the utmost care, both with regard to workmanship and materials. A far superior plan consists in building up the shafts with a sufficient number of square bars; for if, in the slab method, any oxide of iron or dirt

should intrude itself between the joints, the seams will run across the shaft; whereas in the bar method they will be longitudinal. It is, however, very important to avoid attempting to weld too great a faggot of square bars at once, as in that case it frequently happens that at the centre the bars are not welded at all. A few bars should therefore first be welded together, and when soundly joined, other layers of bars may be packed around this central core; the process being continued until the required size is attained, which can thus be effected with perfect success. Another method consists in first making a round core or heart, and packing around this bars of a V form; this method is adopted frequently for forging railway axles, and it was also employed in the manufacture of the monster gun at the Mersey Iron-works. From a paper by Mr. Clay, we find that the method employed in forging this gun was as follows. The gun was built up in seven distinct layers or slabs, the forging occupying seven weeks, and it was found that the metal, after being worked, was improved in strength rather than deteriorated, by the long exposure to great heat. The chief points to be considered by the designer of the gun were, to obtain sound weldings, to place the iron with its fibres in the proper direction for resisting the most severe strain to which it could be exposed, and to take care that while one part of the forging was being worked, other portions were not wasted under the action of the furnace by burning or crystallization.

The first operation was to prepare a core of suitable dimension and nearly the whole length of the gun. This was done by taking a number of rolled bars about six feet in length, and welding them together, and then drawing them out until the proper length was obtained; a series of V-shaped bars were now packed round the core, heated in a reverberatory furnace, and forged under a large hammer. Another series of bars was next packed on, the mass again heated, and worked perfectly sound. Another longitudinal series of bars was yet required over the whole length of the forging, after which the work was about fifteen feet in length and thirty-two inches in diameter, but requiring to be augmented to forty-four inches at the breech, tapering down to twenty-seven at the muzzle. This was accomplished by two layers of iron, placed in such a manner as to

resemble hoops laid at right angles to the axis of the mass, and after two more heatings and careful weldings, the forging of the work was complete. After each important addition, a securing heat was given to prevent flaws.

A great deal has been written at various times on the crystallization of wrought-iron under the action of heat long continued, more especially when the metal is allowed to cool slowly, and also when the metal is subjected to the action of blows frequently repeated; some experiments have, however, tended to disprove the theory of crystallization by heat; but we have seen bars of iron, originally of a tough or fibrous character, snap with a force far below the calculated resistance of the material, the fracture exhibiting a beautiful crystalline texture.

The forms of iron ordinarily obtainable in commerce are as follows: square, round, elliptical, rectangular, semicircular, segmental, channel, T, H, and L iron in bars, also plate and sheet iron; the thinnest being that employed for the manufacture of tin plates.

It is unnecessary here to dilate upon the forging of copper, it being only necessary to observe that it is worked at a low temperature, and that when it is wrought cold it is necessary occasionally to anneal it by heating.

Besides the tools already mentioned, various tongs, and also various special forms, are frequently required to execute hollow or other work, which cannot conveniently be wrought upon the anvil; these are called stakes. Among the swages occur some having at their extremities a conical or cup-shaped recess, intended to complete the heads of rivets; these are termed snaps, and are sometimes worked by machines termed rivetting machines, being attached to piston rods, acted on by pistons working in cylinders of large diameter but with a very short stroke.

CHAPTER III.

ON MOULDING AND CASTING.

For many purposes it is found convenient to produce articles from molten metal, by a process termed casting, which consists in pouring the metal in a fluid state into a cavity which corresponds to the form of the article to be produced. Several methods of producing these cavities are in use, but we shall here confine our attention to the manipulations included under the head of green or baked sand mouldings, loam moulding, and moulding for chilled castings. We will first speak of green sand mouldings.

The first operation to be performed, when it is proposed to make a green sand casting, consists in making a model or pattern of the article to be produced. This may be made of wood; it must be in form similar to the required object, but tapered so that it may admit of being readily removed from the sand in which the casting is to be made; and it must also be larger than the finished article, in order to allow for contraction in cooling, and also for the removal of material in producing finished surfaces. The contraction is, for iron, about a tenth of an inch to the foot, and for brass one-eighth of an inch may be allowed. All apertures in the intended casting are produced by pieces called cores, fixed in the mould; these are retained in position by being made longer than the apertures to be produced, the excess of length being inserted into recesses formed in the sides of the mould. These recesses or hollows are produced by protrusions upon the pattern or model, such protrusions being called core prints.

Cores are also used, under some circumstances, for the production of undercut recesses.

We may perhaps best illustrate the manner in which the

casting is produced, by taking an example, and describing the process required for the completion of such example. Let us suppose that the poppet-head of a lathe, which is of the form shown, Fig. 9, having an aperture running through the whole length of the upper cylindrical part, is required. The pattern will be of the form shown at Fig. 10, being furnished with core prints, as

Fig. 9.

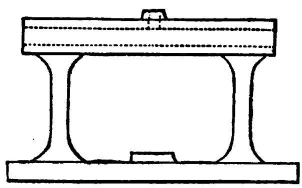
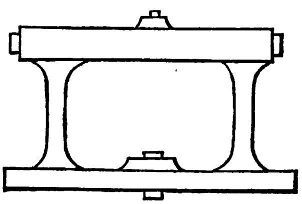


Fig. 10.



shown at each end of the cylindrical part. The process of moulding is conducted in the following manner. Two boxes, having neither top nor bottom, but capable of being fitted together by means of pegs fixed in lugs on one frame, which fit into apertures in lugs on the other frame, together called a flask, are used to contain the sand of which the mould is to be made. One flask is taken and placed with the lugs downwards upon a smooth slab, and filled with moulding sand, which is firmly rammed down. The flask may then be inverted, the sand being retained in the frame by its cohesion and adhesion to the sides of the flask; but when the latter is large, it is, for greater security, furnished with transverse bars. After the frame has been inverted, the upper surface presents a smooth and level appearance, and in the centre of this a hollow is scooped resembling the form of the article to be cast. In this the pattern is bedded in a horizontal position, being sunk in the sand to as nearly as possible half its thickness; powdered charcoal or coal-dust is now sprinkled over the whole surface, and the upper part of the flask adjusted in position; it is then filled up with sand, which is firmly rammed down around the pattern. The two parts of the flask can now be separated, the adhesion of the sand being procured by the layer of charcoal dust mentioned above. The impression formed in the sand of the upper flask is smoothed and repaired, where necessary, by trowels of a suitable form. The sand placed

in the first frame is now broken up, the frame which served as the top of the flask placed with the cavity uppermost, the pattern placed in the cavity, the empty frame fitted on, and the whole filled up as before. The flask is then again taken in pieces, both cavities repaired where necessary, and openings made from the cavity in the upper frame, through to the surface of the sand. These are called gates, or gits, and serve, some of them, for the admission of the molten metal, and others afford egress to the air in the cavity and the gases generated by contact of the hot metal with the sand. The core, previously made, of tough loam with chopped straw or other filamentary material, and dried, is now inserted in the core prints; the flask is then put together, the two parts being secured by pins or wedges passed through apertures in the extremities of the pegs fixed to the lugs of the lower frame. The metal may then be cast. When the casting is sufficiently cool the mould is broken up, the superfluous metal knocked off; and when the casting is quite cool, the false seams are cut off, the core cleared out, and the hard sandy coating rubbed smooth with a piece of oven-coke.

We may now mention a few particulars to be observed in the general preparation of moulds. Ample space for egress of gases must be allowed, wherefore it is desirable to pierce the sand to within a small distance of the cavity, by means of a stiff wire; also to form a sufficient number of gits. The sand should be of open texture, but of a binding character, otherwise the casting will be apt to scab,—that is to say, there will be a liability in the sand to scale off the surface of the mould, and rest on the surface of the casting. If sufficient egress be not allowed for the air, blow-holes will occur within a short distance of the surface of the casting, thereby materially reducing its strength. It is usual to tap the pattern with a hammer in order to loosen it, previous to withdrawing it from the mould, thus preventing the risk of damage to the mould, and for this purpose wires are sometimes screwed into the pattern, which protrude through the surface of the sand and the upper part of the flask. Very heavy patterns may be removed from the sand by the united efforts of several men, each lifting the pattern with one hand while with the other he taps it with a light hand-hammer.

If the sand be used too damp, hard places will be formed in

the casting, thereby adding materially to the difficulty of subsequently working the metal.

Moulding in baked sand is conducted in a manner similar to the above; but the sand is used in a more moist condition, the mould being subsequently dried in a suitable furnace. Moulding in loam is conducted in a manner quite different from the method employed for moulding in green sand—no pattern being used; we may take as an example of this class of moulding the formation of a hemispherical melting-pot. A cast-iron ring is laid down on the foundry floor, and upon this a brick dome roughly approaching the internal form, is erected, an aperture, however, being left at the upper part. A quantity of loam, formed of clay, water, sand, and cow-hair, after having been reduced to a paste and thoroughly kneaded in a pug-tub, is laid on the brick dome with trowels and smoothed with the hand; a fire is then lighted within the dome by means of apertures left on the cast-iron ring, a stratum of fine loam laid over the first layer, and formed to the exact contour of the interior of the vessel by means of a scraper of suitable form, attached to a vertical spindle passing through the centre of the dome, and supported in bearings at the top and bottom, so that the scraper can be caused to revolve. The required form having been obtained, the scraper is removed, and the mould allowed to dry; after which it is thickly painted over with a mixture of charcoal, clay, and water, applied with a brush; another layer of fine loam is then applied equal to the thickness of the required article, and to it is imparted the exact form of the exterior of the vessel, also by means of a scraper. The whole is then again dried, the spindle being removed, and the aperture in the top of the dome filled up. The mould is again painted. Another ring is now laid down around the former and adjusted to it by steady-pins; the mould is covered with a layer of fine loam and then with a thicker stratum of coarse loam, and surrounded by brick-work. We shall now have an interior dome and an exterior shell, containing between them a quantity of loam corresponding to the thickness of metal in the required vessel. The outer shell is removed by lifting the outer ring by means of a crane, the painting of charcoal paste preventing its adhesion to the substratum. It is repaired with trowels, the intermediate thickness of loam is

then broken off, and the surface of the interior dome smoothed and repaired where necessary. Gits are prepared in the outer shell, which is replaced, and the metal cast. As soon as the casting has become sufficiently cool the brick-work of the interior dome is loosened, in order to allow of the free contraction of the casting.

All moulds having the form of solids of revolution can be thus produced by scrapers, but other forms must be obtained by aid of templates, or the workman must depend upon the correctness of his own eye.

We have yet to mention chilled casting. This consists of substituting metal surfaces for sand, wherever the casting is required to be peculiarly hard, this effect being produced by the rapidity with which the heat is conducted away by the metallic mould.

For large castings the metal should be melted in reverberatory furnaces; for smaller ones a small kind of blast-furnace called a cupola is used. This consists of a low brickwork foundation upon which a sheet-iron cylinder is placed, which is lined with refractory sand, and surmounted by a low chimney or conical hood; holes are formed in the side of the cylinder to admit nozzles, through which the blast may be supplied, and also to allow the molten metal to be drawn off. The fuel and metal are supplied in alternate layers, and the metal as it melts accumulates in the bottom of the furnace. The charges are in the proportion of twenty-five coke to a hundred of iron; and the latter begins to melt about twenty minutes after its introduction into the furnace. For large and heavy castings the moulds are sunk in the floor of the foundry, and the metal run into them from the cupola, along channels in the sand of the foundry-floor. For small castings the molten metal is carried in ladles lined with refractory clay; and for larger castings, large ladles or shanks, moved about by a crane, are used. Every casting requires more metal than is requisite to fill the mould, the excess going to form false seams, &c., and besides this there is an actual loss of six per cent. of the metal; so that after deducting all losses, each hundredweight of coke melts about three hundredweight of pig-iron. The following are the dimensions of an average sized cupola, capable of melting five tons of metal at one time: height,

nine feet; external diameter, five feet; internal diameter, three feet six; height of first tuyere hole, two feet six inches; distance between tuyeres, fifteen inches; diameter of nozzles, from three to five inches; speed of fan, seven hundred revolutions per minute, to maintain which a power of three horses will be required.

CHAPTER IV.

ON CUTTING TOOLS.

In the present chapter we purpose to describe the various forms of tools used for cutting and abrading metal. The first of these to which we shall direct our attention are files. The general form of these is too well known to require any detailed description at our hand. The teeth are produced by making a series of cuts with a chisel along the whole length of the file, and dividing the ridges thus raised into teeth by other cuts crossing them at an angle, after which the tool is hardened. In cutting square and flat files it is usual to leave one side smooth to rest against the work without injury to it, thus forming a safe edge. When the file is only cut in one direction it is termed a float. A rasp has various isolated points raised upon its surface. The variety of files is almost endless, depending as they do upon the nature of the work for which they are required; but only a few of these are necessary for the execution of those branches of mechanical manipulation of which we treat. These are divided into three classes, viz.: taper, hand, and parallel. Those of the first description taper to a point, the second are formed with sides nearly parallel, and the third quite parallel, so as to be of the same thickness throughout. Files are also distinguished according to the fineness of their teeth, as follows: rough, bastard, second cut, smooth, and dead smooth. Taper files vary in length from four to twenty-four inches, are rectangular in section, and rounded in width and thickness. Hand-files are more parallel in width, and less taper in thickness than the foregoing, and are commonly used for flat surfaces when greater accuracy is required than can be obtained with ordinary taper files. Cotter files vary from six to twenty-three inches in length; they are employed for filing grooves for cotters, keys, or wedges, used for fixing wheels upon their shafts. They are narrower than hand files, and nearly flat on their sides and edges.

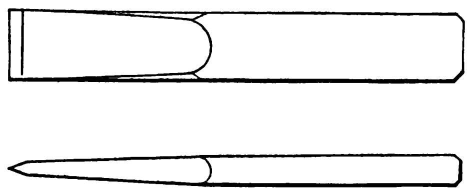
Pillar files are similar to hand-files, but much smaller, varying from three to ten inches in length; they are usually formed with one safe edge. Half-round files have a segmental section, varying from one-quarter to one-twelfth of a circle, one side of the file being convex the other flat; their length varies from two to eighteen inches. Crossing files, or double half-round, are circular on both sides. Triangular, or three-square files, are made from two to sixteen inches in length; they are used for internal angles, for clearing out square corners, and for sharpening saws. Round files are usually taper, from two to eighteen inches in length, being used to enlarge round holes. Square files vary from two to eighteen inches in length, and are generally taper, having one or more safe edges; they are principally used for small apertures.

We will now proceed to speak generally of the angles of cutting tools. Scrapers are usually formed with edges contained between facets, making together an angle of from 55° to 60°. As a general rule, the softer the material the more acute may the angle of the cutting edge be: and the angles vary, for brass, copper, iron, and steel, from 65° to 90°; those for iron varying between 85° and 90°. Great care must be taken in order to obtain the angles of the cutting edges well defined, otherwise their action will not be satisfactory.

We will now speak in detail of the various cutting tools with which the mechanical engineer must be provided; commencing with hand tools, and subsequently describing machine tools.

Fig. 11 exhibits two views of a cold metal chisel of the form

FIG. 11.



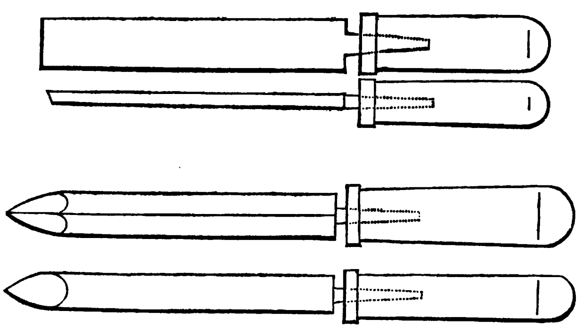
most commonly used, having a wide edge. These are ground on both sides to an angle from 70° to 80°; for some particular purposes being even more obtuse; they are tempered down to a

deep straw colour, and when in use are held in the left hand upon the work undergoing manipulation, and driven by blows struck with a hand-hammer held in the right hand. A similar form of chisel, attached to a hazel rod and driven by blows of a sledge-hammer, is employed by smiths for cutting hot iron; but it is shorter and of a stouter make, being furnished with a wider edge. There is another form of chisel occasionally used for cold metal, having a semicircular edge; this is ground on the flat side and is used for clearing out grooves of a circular or elliptical section.

Small hand punches are also frequently employed for piercing thin metal, being formed of round steel, tapered off and ground flat at the end. Centre punches, which are used for marking work where holes are to be drilled, produce a conical or countersunk recess, and are themselves formed of round steel, tapered and ground to a conical point, with an angle of about 80°.

Scrapers are usually made in one of two forms: an old parallel file is taken, the teeth are ground off, and the end is ground smooth, so as to produce an angular scraping surface; or an old three square file is used, the teeth being ground off, and the faces near the extremity ground convex, so as to terminate in a point, thereby forming three scraping edges, each having an angle of 60°. The two forms of scrapers are shown in the accompanying Fig. 12.

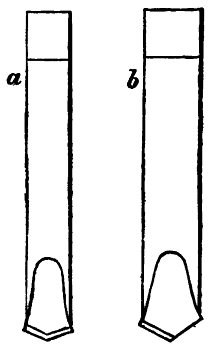
FIG. 12.



We may here mention among fitters' tools, the metal saw. It is a kind of frame saw, consisting of a thin narrow blade, furnished with teeth, tightly stretched in an iron frame. Saws of this description require frequent sharpening.

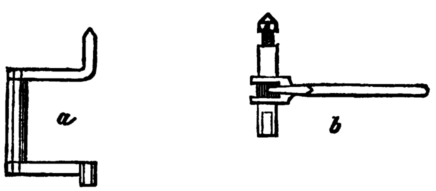
Small drills worked by hand are in constant requisition. They are of two sorts : those that are worked with an alternate reciprocatory motion, ground on both sides, so as to scrape equally well in both directions, shown at *a* in Fig. 13; and those worked with a continuous circular motion, ground at one side only, shown at *b*, so as to cut in one direction; drills of the former description are usually fixed in a shaft, the tail end of which is conical, and rests in a counter-sink formed in a breastplate worn by the operator, through which the requisite pressure is imparted. Upon the shaft is fixed a sheave or pulley, around which the string of a steel-bow passes; by imparting an alternate rectilinear motion to the bow, the wheel, shaft, and drill are caused to revolve alternately in opposite directions, thereby penetrating the material which is being operated upon.

Fig. 13.



The second class of drill is usually employed either in a brace, consisting of a crank, as shown at *a* Fig. 14; but when the hole

Fig. 14.



is to be drilled in a position which does not allow sufficient room for the brace, another kind of stock, called a ratchet brace, *b*, is made use of. This consists of a stout shaft, furnished at one end with a socket to receive the tang, or tail-end of the drill, and at the other with a screw, on the head of which is a hard conical point, and by means of which the requisite pressure is imparted to the drill; in the centre of the shaft is a ratchet wheel, firmly fixed, and embraced by the forked end of an arm or lever, furnished with a pall, acted upon by a spring, which causes it to fall into the teeth of the ratchet wheel; thus, when the arm is

moved in the direction in which the drill is made to cut, the pall catches in the teeth of the ratchet wheel, and drives the wheel forward, but on reversing the motion, the pall slides over the teeth, leaving the drill stationary.

A great variety of minor drill stocks have been devised, but they are calculated rather to entertain the amateur than to render efficient service to the practical engineer; we shall, therefore, not encumber our space with a description of them.

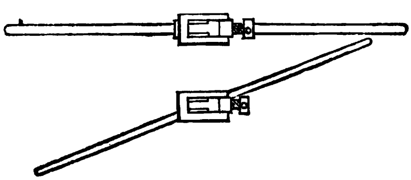
There are a class of scraping-tools, known as broaches, or rhymers, employed for cleaning out circular holes; they consist of taper, triangular, square, hexagonal, or octagonal tools, of which the thickness is inconsiderable, when compared with the length.

Square holes are cleared out by means of steel drifts, consisting of taper steel bars, in which notches are filed at regular intervals, in order to give rise to cutting edges. A drift is forced through the aperture to be cleared by striking it with a hammer, and as these tools are made very hard, breakage frequently occurs.

We must now proceed to describe the methods by means of which screws are produced by manual labour. For the smallest screws a plate of dies, called a screw-plate, is employed; it consists of a plate of steel, in which threads have been cut, which are at certain parts filed away, in order that cutting edges may be formed, and also to afford a means of egress to the metal removed from the screw which is being cut. By means of this apparatus, the threads on a screw are partly cut, and partly squeezed up, being therefore not so perfect as those produced by the action of point tools, which will presently be described.

For the production of larger screws, such as the threads of bolts, dies made in two or more parts are used, the cutting

Fig. 15.



edges appearing on the edges of the dies. These dies are used by means of stocks of the form shown, Fig. 15. In the centre

of the stock is a rectangular opening containing V-shaped ridges, which, fitting grooves in the dies, retain them in the stock. At one end of the rectangular opening, the ridges are cut away, in order to allow of the introduction of dies as required, which dies are adjusted by means of a set screw, in some cases formed on the end of one handle, of which construction we do not, however, approve, deeming it preferable to have the handles firmly fixed, the dies being set up by separate screws.

Having concluded our remarks upon the means used for producing small solid screws without employing machinery, it is necessary to give an account of the method employed in making small hollow screws, or nuts. These are produced, first by drilling, and then by cutting threads by means of a hard steel screw, which we will now proceed to describe. Upon a piece of the best round steel, accurately turned, a screw is cut with great care, so as to be truly formed throughout; a portion of this thread is then removed by filing three or four grooves along the sides of the top, cutting edges being thereby formed, and a means of egress afforded the particles of metal cut away; the thread is also reduced towards the point of the top, thereby imparting to it a taper form, in order that it may gradually cut the thread, so that it may not overstrain either the tool or the material being wrought. Usually, for tapping a nut, two taper taps, and one plug, or parallel tap are used, being formed with a square head, which fits a rectangular opening in the centre of a stock, or tap-wrench, which is handed round in the same manner as a die-stock. Oil is used for lubricating these tools, in order to prevent their becoming heated.

A pair of shears for shearing metals is also used; they are precisely similar in their action to ordinary scissors, their edges being ground to an angle of about 85°. The blades are very short, and broad in proportion to the length of the shears. The ends of the handles are curved round, so as to meet and prevent the shears from closing too far.

There are other tools used by fitters, but as they are not, properly speaking, cutting tools, we shall defer the description of them to the chapter wherein we propose to treat of the manipulations included under the general head of fitting.

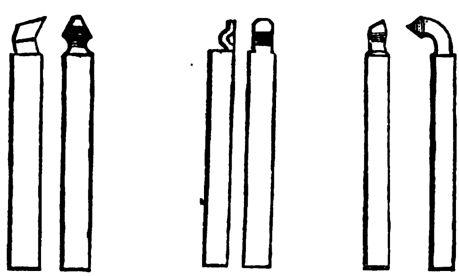
We will now proceed to describe the forms of the various tools

used for operating upon metal by means of machinery. The machines themselves will be described in the following chapter.

The first tool of which we shall speak is known as the point tool; it is forged from square steel, as in fact are most of the machine tools. Two views are shown of it in the accompanying Fig. 16. This tool produces a surface consisting of very narrow grooves, the metal being generally removed by the action of the point and one side of the cutting edge; it is used in the lathe, in the shaping machine, and in the planing machine.

Another tool has been derived from that which we have just described, which is most frequently used in the lathe, for taking large cuts, whereby the greater bulk of the superfluous metal is removed. This tool may be said to consist of one side of the point tool, the whole of its cutting edge being inclined to the axis of the work.

FIG. 16. FIG. 17. FIG. 18.



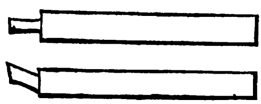
The next tool which we have to mention is the spring tool; it is formed with a spring or bend, as shown in Fig. 17, which enables it to yield to any hard particles which may occur in the metal being wrought, instead of tearing them out after the manner of the point tool. The spring tool is also much broader, somewhat rounded on the end, in order to prevent the danger of its corners from cutting too deep into the work. Hence this tool produces fewer ridges than the point tool, and such as do occur are more gradual in their ascent; the point tool is, however, capable of executing the work more accurately.

We may next speak of the side tool used for boring small cylinders, and also for cutting internal screws. A plan of this tool is shown in Fig. 18; when intended for boring, it is usually

formed with a cylindrical part drawn out behind the cutting edge, in order to allow it to pass freely to the bottom of the cavity. When the tool is intended for cutting internal screws, the cutting edge should be made to protrude further from the central axis than when the tool is employed for boring purposes.

Fig. 19 represents a parting tool. It is used for cutting through or dividing work, and is made widest at the cutting edge, in order that the metal behind may not come in contact with the

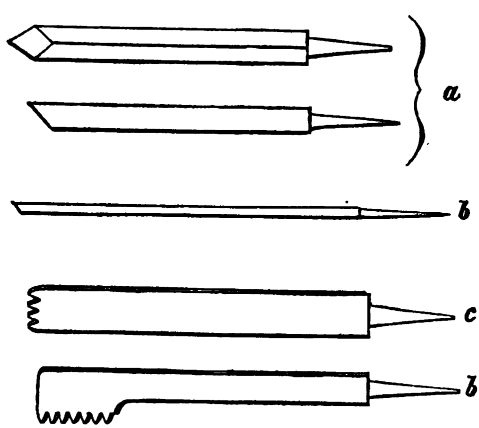
Fig. 19.



sides of the cut. A tool very similar in form to this is used for cutting the threads of screws, its form being square, V, or otherwise according to the form of the thread required to be cut.

A number of hand tools shown at Fig. 20, are used with the lathe: *a* being termed a graver, *b* a flat tool capable of

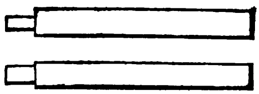
Fig. 20.



springing slightly, *c* a screw tool, *d* an internal screw tool. Following the points of these screw tools, are threads which determine the pitch of the screw being cut.

We have yet to notice the slotting tool, which is used in the vertical motion slotting machine; it is of the form shown, Fig. 21, and is chiefly used for slotting out wheels to receive the keys or wedges by which they are fixed to their shafts.

FIG. 21.



The machine tools already mentioned, are used with the turning lathe, planing machine, and slotting machine; but there are also many forms derived from these used, to effect special purposes, which, however, are so similar in principle, that it is unnecessary here to dilate upon them.

There are numerous small tools or cutters used in the turning lathe and drilling machine, principally for boring purposes: some of these are shown at Fig. 22. The remaining sketches in this

FIG. 22.

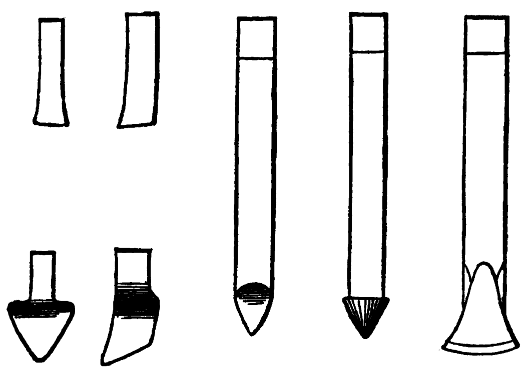


figure show various forms of drills used in the lathe and drilling machine.

Face and edge cutters of various forms are employed for grooving and trimming work; they are made by raising a number of ridges or cutting edges on the surface or periphery, as the case may be, of discs. Punches, shearing edges, taps, &c. used in machines, are similar in their general form to the same tools used by hand, but stronger, and the taps used for making screw tools are called hobs.

CHAPTER V.

ON WORKSHOP MACHINERY.

In the present chapter, we propose to describe and illustrate samples of the machinery generally required in the factory of the mechanical engineer. It would appear most reasonable first to describe the steam-engine, by which the workshop machinery is driven, but we shall not do so in this place, as the various forms of steam machinery are fully described in a subsequent part of this work. We may also here observe, that as the forge and steam-hammer have been already described, we shall not here refer to them.

The first machine to which we shall turn our attention, is the lathe, which is perhaps the most useful implement with which the mechanical engineer is provided. Plate V. represents a double-geared lathe, driven by steam power; it has eighteen-inch centres; the bottom piece is the bed of the lathe, the surface of which is very accurately formed, by means to be hereafter described; upon this bed at one extremity is mounted a heavy head stock, which carries the gearing by which the lathe is driven; this gearing consists of two mandrils, one of which carries diminishing riggers, and two toothed wheels; the other shaft carries also two toothed wheels, gearing with the former. When greater variations of speed are required than can be attained by the speed riggers alone, these are loosened from the shaft by slacking a nut, which previously held them tight, up to the front spur wheel on the main shaft of the head stock, and the lathe is driven through the intervention of the spur gearing on the other shaft. The main shaft is called the mandril, and is in the centre of the lathe. At its extremity is a pinion, which gears into wheels by means of which a long screw is driven; this screw runs the

entire length of the lathe bed, and serves to propel at an uniform speed the slide rest which we now proceed to describe. It consists of a stout foundation piece, which fits accurately the top of the lathe bed, admitting of a sliding motion upon it. Upon this foundation piece is placed another slide as shown, worked by a screw attached to the foundation piece: its motion is at right angles to the lathe bed. Above this is a smaller slide, also worked by a screw, as shown; it moves parallel to the lathe bed, but admits of adjustment to any required angle. On the top of this slide the cutting tools are held by means of short bars pressed down upon them by nuts working on studs, as shown. The entire slide rest admits of being moved along the bed of the lathe, by a handle acting upon a pinion gearing in a rack attached to the lathe bed. In order to move the slide in this manner, it is necessary to throw it out of gear with the long screw, or leading screw, as it is termed, which is effected by opening the gearing nut, made in two parts, in order that it may admit of this movement. At the further end of the lathe bed, is shown another head stock called the poppet head; this, like the front head stock, is furnished with a mandril, at exactly the same height from the lathe bed. The mandril in this head is hollow, and admits of longitudinal motion, by means of an internal screw, worked by the hand wheel shown at the back of the head. The poppet head is also capable of sliding on the lathe bed, being secured in any required position by means of a clamp drawn up tight against the lower side of the top of the lathe bed, by means of the bolt and nut shown. Each of the mandrils is fitted with a conical centre, whereby work to be operated upon is supported. On the mandril of the front head is shown a disc or chuck, whereby the work in the machine is caused to revolve with the mandril. Some chucks are simple perforated discs, perforations allowing bolts to be passed through, by means of which the work is secured. Other chucks are made with L-shaped pieces of iron, or dogs, as they are called, sliding on the surface, their position being regulated by means of screws fixed in slots in the chuck, and gearing in nuts at the backs of the dogs. A cup chuck is a metal cup, having in its periphery six or eight set screws, by means of which articles to be turned or bored are held. This, like the other chucks, has an aperture bored through its centre,

screwed inside, in order that it may be attached to the screw nose of the mandril.

Above the latter is shown the overhead driving gear. It consists of a short shaft, supported in bearings, carried by two hanger brackets. On this shaft are fixed first, a pair of large fast and loose riggers; second, a pair of small riggers; thirdly, speed riggers. The latter are connected with the speed riggers on the mandril of the front lathe head, whilst the fast and loose pulleys, large or small, as the case may be, are connected by a strap with the maindriving shafts of the factory; when the lathe is to be driven, the strap is placed upon the fast pulley, which being firmly keyed to the short shaft, the latter is caused to revolve. When the lathe is to be stopped, the strap is shifted to the loose pulley. The strap is shifted by means of a fork, fixed on a sliding bar, as shown, which may be moved by means of a long lever or handle.

For boring large cylinders in the lathe, a boring bar is employed, being placed between the centres and within the cylinder to be bored, which latter is bolted down to the lathe bed. Upon the boring bar is a disc, called a boring head, which carries small cutters to operate upon the interior of the cylinder to be bored; it is moved longitudinally by means of a screw let into a groove in the boring bar, this screw being caused to revolve by means of gearing at one extremity. The lathe may be supported on iron frames or timber blocks as may be most convenient.

We will now proceed to describe the slotting or grooving machine, of which a view is shown (Plate V.) This consists of a stout frame, carrying at its lower extremity a table, which admits of motion in three directions—forwards, laterally, and a revolving motion. To the upper part of the frame guide blocks are attached, and within these guide blocks a square bar moves vertically. Motion is imparted to this bar or slide by means of a link, the upper extremity of which is attached to a pin, which forms the prolongation of a stud, bolted to the vertical slide, which stud is, however, adjustable by means of a screw working within the slide. The lower end of the link is attached to a pin capable of adjustment in a groove running diametrically across a disc. By the adjustment of the position of this pin on the disc, any stroke of the vertical slide up to about fourteen inches may be obtained. The grooved disc is carried by the end of a shaft, to the other

extremity of which is attached a large tooth or spur wheel. This large spur wheel gears with the pinion on the driving shaft, the motion of which is rendered more uniform by a fly wheel firmly keyed on to it. The apparatus is fitted with speed riggers and overhead motion, similar in principle to those furnished to the lathe already described. On the secondary shaft, that which carries the grooved disc, is fixed a cam, as shown, consisting of a cylinder, having on its periphery a groove formed like a screw, returning into itself. This groove is fitted with a pin, carried at the extremity of one arm of a bell crank. To the other arm of the bell crank is attached by a pin a link, the lower extremity of which is connected with a second crank, carrying also a pall, by means of which a feed or self-acting motion is given to the table for the machine; for as the cam revolves the pall moves backwards and forwards, sliding over the teeth of the wheel in one direction, and pushing the wheel before it on its return. The wheel can thus be made to revolve by intermittent movements in either direction, by turning the pall on either side of the centre as may be required, or, if necessary, the pall can be thrown out of gear altogether. There is another link proceeding from the bell crank, which carries this pall to an arm working upon the centre of another wheel, which is also fitted with a pall, in order to obtain self-acting motion of the table laterally. To the lower extremity of the vertical slide are fitted two clamps for holding the cutting tool as shown. The machine here illustrated admits of articles of very large diameter, nearly eight feet, being intended to slot railway wheels; but for other purposes similar apparatus are made with less clearance.

Plate VII. exhibits a very simple but useful form of shaping machines. It consists of a stout table or foundation-piece, to one side of which is attached a table or chuck, to hold work whilst it is undergoing the process of planing. This table may be raised and lowered by means of a vertical screw, being kept in position by guide blocks working in two vertical screws. To the opposite side of the foundation-piece brackets are attached, carrying a short shaft, on which speed riggers and spur wheels are fixed. One of those spur wheels gears in a larger wheel placed above and behind it. This wheel is fixed on a shaft carrying a slotted disc, which, by means of a link, similar to that described as appertaining to the slotting machine, drives a horizontal slide. To

the extremity of this slide, by means of set screws, shown, the cutting tool is held in a frame capable of oscillating on an axis, in order to allow the cutting tool to rise on the return stroke, thereby preventing the risk of breakage. The tool is capable of adjustment vertically by a vertical screw, and angularly by a tangent screw and quadrant, as shown in the front elevation. The horizontal slide, with the cutting tool and gearing, admits of a lateral motion, being fitted accurately to the upper surface of the foundation piece, this lateral motion being imparted to it by means of a screw and nut. All the movements in this machine may, if it is desired, be fitted with feeds, in order to render it self-acting. We may here observe that the grooves in the chuck or table are undercut, in order to admit the heads of bolts, whereby the work is securely fixed. The usual driving gear is furnished to this machine.

We will now proceed with the description of a drilling machine, illustrated Plate VIII. This machine consists of a stout frame, carrying at its lower part a table or chuck capable of vertical motion, and at its upper part two arms, supporting the drilling gear. The driving riggers and accompanying gearing are similar to that exhibited on the head stock of the lathe previously described; but motion is communicated from the horizontal mandril to the vertical spindle by means of bevelled or mitred wheels, as shown. The vertical spindle is hollow, containing the drilling shaft, which has at its lower extremity a socket for the drills, and at its upper extremity a screw by which it is raised or lowered. At the back end of the horizontal driving shaft are some small speed pulleys connected by a strap with a similar series on a parallel shaft placed lower down, and having at its front extremity a short screw, which gears with a worm wheel on the lower end of a vertical shaft, parallel with the drilling spindle. The upper end of this shaft carries a spur wheel, which gears with another fixed to the nut, by which the screw attached to the upper end of the drilling-spindle is raised or lowered; thus the machine is made self-acting. To the lower end of the smaller vertical shaft is fixed, as shown, a hand-wheel, so that the feed may be applied by hand, if required. This machine may be used either with drills or small boring bars, carrying cutters fixed in slots. The driving gear is of the usual form.

Plate IX. represents a planing-machine. It consists of a stout bed or foundation piece, furnished with two grooves. Upon this bed slides a table furnished with pieces, which fit the grooves. This table is caused to move rectilinearly by a pinion acting upon a rack attached to its lower side. This pinion is driven by gearing connecting it with a driving shaft having three wheels or riggers, the centre one being loose and the outer two being so arranged that when the strap is on one wheel a slow motion towards the cutting tool is obtained, and when it is upon the other wheel a rapid motion from the cutting tool is obtained. The strap is shifted at the end of each stroke by means of a pair of stops, clamped to the bottom of the table. These stops strike an arm on a shaft, throwing it backwards and forwards, whereby the motion is reversed and the requisite feed imparted to the cutting tool. Near one end of the bed a pair of stout frames are fixed, one on each side, connected at the top by a strong bracing piece. The front faces of the upright posts of these frames are accurately finished, and carry a long transverse slide, which may be raised or lowered by means of vertical screws outside the post, worked by bevil wheels gearing into others, fixed on a transverse shaft passing over the top of the frames. On the centre of the transverse slide is the tool holder, fitted on a slide with a vertical adjustment, and also an angular adjustment. This slide may be moved horizontally or vertically by the self-feeding apparatus mentioned above; the former being obtained by means of a screw in the transverse slide, and the latter by a sliding bevil wheel on a shaft in the same, which gears with another bevil wheel on the vertical adjusting screw of the tool holder. In this apparatus, as in the shaping machine, the tool rises at the return stroke of the table, the tool holder working upon gudgeons. In order to plane the sides of wide work, tool holders are attached to the vertical posts of the side frames or standards. The feed is applied by means of palls, the arms to which they are attached being worked by a vertical rod, which rises and falls according to the motion of the shaft, by which the strap is shifted at the termination of each stroke.

Plate X. exhibits a view of a punching machine of peculiar construction. On one side of the apparatus is a punching, on the other side a shearing arrangement. These are worked by levers,

as shown, the punch and upper shearing edge being alternately raised and lowered by means of the cams, shown in dotted lines. These cams are upon a shaft carrying a large spur-wheel, to which motion is communicated by a pinion on the driving-shaft.

Punching and shearing machines are generally made with vertical slides, as in the above apparatus; which, however, are driven by eccentrics working in rectangular spaces within them, of such dimensions that the width of the aperture allows for the lateral play of the eccentric; whereas the height of the aperture is equal to the diameter of the eccentric.

Messrs. C. De Bergue and Co. have patented an exceedingly ingenious punching and shearing machine. It consists mainly of a stout frame, containing within it a rocking-frame worked by an eccentric. The lower part of this frame is wide, carrying on one side a shearing edge, on the other a punch.

Mr. Cochrane, of the Woodside Iron-works, Dudley, has constructed some drilling machines, containing eighty drills each, to drill the plates of the railway bridge now in construction at Charing Cross. The feed is applied by hydraulic pressure. It has been found that with eighty one-inch drills five-eighths of an inch plates could be economically perforated in fifteen minutes.

Besides the machinery already noticed, machines are made in which nuts and screws can be produced. They are fitted with easily moved slide rests, which rests are drawn along by the action of the threads following the cutting edges.

The nut-shaping machine consists of a table, to which is fitted a head stock and driving gear; upon the mandril is a rotatory cutter, with cutting edges on its face and also on its periphery. In front of this cutter is a circular piece of metal, formed with six or eight equidistant notches in its edge, into which a pall may be caused to fall, to retain the plate or chuck during the operation of facing one side. The top of the nut is faced by the periphery.

A dividing engine is a species of lathe with a divided chuck, palls falling into the divisions.

In addition to the machines described, other apparatus are frequently required for the execution of work of a peculiar character.

Some minor machines will be described whilst treating of the manipulations conducted in the workshop.

CHAPTER VI.

ON MANIPULATION.

In the present chapter we purpose to describe the manipulations with which the mechanical engineer must be acquainted in order to reduce rough castings and forgings to accurate forms, and to fit together and erect the machines of which those forms are the elements.

The most convenient method of describing these manipulations will be to commence with the rough castings and forgings, and follow them through the various processes which they must undergo previous to their completion. Let us commence with the casting of a steam-engine cylinder, with its covers and slides; the cylinder may first be fixed upon the bed of the lathe and bored, the boring being effected in the following manner. Let the boring-bar be placed between the centres, and fitted with a boring-head, in diameter nearly equal to the internal diameter of the cylinder. In this boring-head several cutters are fixed, the angles of the cutting edges being nearly 90°. By this means we may remove the greater portion of the excess of the material; but in taking the last cut, the lathe must not be stopped after the commencement of the cut until the completion of the same, and the cut should be taken by a point tool, which will give most accurate results; for although the interior of the cylinder may look and feel rough, it will be found after a few days of active working to have worn smooth, which will not occur so satisfactorily if the cylinder be improperly bored.

The ends or flanges of the cylinder may also be faced up before removing it from the lathe by cutters fixed to a slide attached to the boring-head.

The cylinder having been bored, it may be removed to the

planing machine, where the port faces may be planed; in this, as in the last operation, the finishing cut should be taken by a point tool. These port faces will subsequently require further treatment to reduce them to a plane surface as nearly as possible; but we will now consider the preparation of the cylinder covers.

Each cylinder cover may be chucked in an ordinary lathe, turned on the edge, faced on the under side of the flange, and the upper cover bored out at the stuffing-box. The covers may then be placed in position upon the cylinder, and the holes by which they are to be connected with the latter drilled under the drilling machine.

We will next speak of the operation of facing the ports; we must, however, first pause to mention the instruments used by the engineer to measure and mark out his work. The first of these, the dividers or compasses, are too well known to need any description at our hands. The callipers, intended for taking diameters and thicknesses, are similar to compasses, with curved legs; for taking thicknesses and diameters external, the legs should be bowed outwards, but for taking the width of recesses and internal diameters, they should be bowed inwards; but one pair may be made to answer both purposes. The mechanic will also require squares, straight-edges, and planometers, or surface-plates. Squares may be tested by ruling a very fine line, holding the pencil close against the edge of the square, then reversing the square, and drawing another fine line coinciding at some point with the former; then if the lines coincide throughout, the square is correct, if not, the contrary is the case. The straightness of the blade of the square may be tested in the same way as that of an ordinary straight-edge, which is effected thus: rule a line as before, after which turn the straight-edge end for end, make the two ends of the straight-edge coincide with the extremities of the line already ruled, then rule another fine line; if this coincides in every part of its length with the first line, then is the straight-edge accurate; but if otherwise, the two lines will contain a space, and as two straight lines cannot contain a space, the edge must be inaccurate.

It may be interesting here to describe the method to be pursued in making a straight-edge. Three straight-edges should be made together; for this purpose three strips of metal are laid side

by side, and planed as true as possible; we will number them one, two, and three. In the first place, numbers one and two are filed and scraped until they accurately fit each other, so that, when held up to the light, no light can be seen between them. Numbers one and three and two and three must also be made to agree; then, when any two of the straight-edges, taken indiscriminately, accurately coincide, all the straight-edges are perfectly true.

We will now proceed to describe the planometer, or surface plate, in reference to its construction and use. Two should be made together; they should consist of a flat cast-iron plate, supported by webs at the back; the two plates are planed with a point tool, then filed and scraped until, if a straight-edge be laid upon it in any position, the light cannot be seen between the straight-edge and surface-plate. Ruddle, or other red colouring-matter, is then rubbed upon one of the two surface-plates, and the other surface-plate is placed upon it and moved about, when it is evident the highest points, or points of contact of the two plates, will be coloured; these are scraped down, and the process repeated continually, until upon rubbing the plates together the colouring-matter becomes uniformly distributed upon the entire surface.

In the same manner as the planometer is made, the port faces of the steam-cylinder are made true, ruddle being rubbed on the planometer, which is then moved about upon the port-face; the parts of the port-face which become coloured represent the highest points, which are therefore scraped down, and the process repeated continually until the bearing is uniform, which is indicated by uniformity of the colour taken up by the port-face. The slide which moves upon the port-face is then, by means of the planometer, brought to as true a surface as possible, after which the slide and port-face are by a similar method made to bear accurately upon each other.

If any part of the cylinder be of intricate curved form, the shaping-machine may in many cases be employed with advantage to operate upon such part; if, however, this apparatus is not applicable, then must the surface be finished by hand.

We now proceed to consider the completion of the piston and piston-rod. The body of the piston will consist of a short cylindrical piece, or disc, having on its lower surface a flange, and

being fitted at its upper surface with a moveable flange, called a junk-ring, this junk-ring being retained in position by bolts. Between the two flanges, and around the body of the piston, are placed elastic packing-rings of cast-iron; these rings are cut thicker on one side than on the other, in order that they may be equally elastic all round. The upper and lower surfaces of these rings must be accurately fitted by scraping to the flanges of the piston; the body of the piston is bored in the centre in order to allow of the attachment of the piston-rod, which is fixed in position by a bolt, or nut, or by a key, or other convenient means.

We next come to the construction of the piston-rod, which is usually made of round iron. A piece of suitable dimensions having been chosen, the centre of each extremity is found as nearly as possible, marked with a centre punch, and by the indentations thus made the bar is suspended between the lathe-centres and caused to revolve while a piece of chalk is held against it. If it does not run truly between the lathe-centres, the highest parts will be indicated by a chalk-mark. The bar is then removed from the lathe and re-centred, and the operation repeated until the centres are sufficiently accurate in position, after which a ring is passed over one end of the bar, and firmly held upon it by means of a set screw: this ring has at one part of its periphery an arm, and is called a carrier. The bar is then replaced in the lathe, with the carrier next to the chuck on the lathe mandril, so that the work may be caused to revolve by means of a bolt attached to the chuck, which comes in contact with the arm on the carrier.

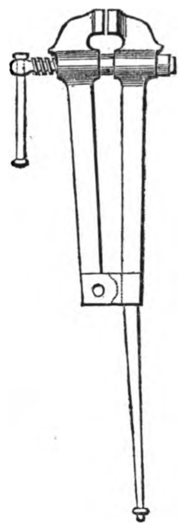
The greater part of the superfluous metal is then removed at one cut by means of a point-tool, after which the remainder of the metal over and above the necessary quantity is removed by a lighter cut, when the piston-rod may be fitted to the piston.

We will now describe the remaining implements used by the fitter and erecter for the completion of work which has already been operated upon in the lathe or other machine.

The first and most indispensable piece of apparatus is the tail-vice, or smith's vice, shown Fig. 23. It consists of a large vice with long jaws, one of which is prolonged into a tail, the lower extremity of the tail being fixed in a block attached to the floor;

at the upper part of the vice, just beneath the screw by which the jaws are closed, is a strip of iron, by means of which the vice is firmly screwed to the work-bench. The vice should be furnished with pieces of tin and copper, to hold work which would be damaged by the teeth of the vice; also, for a similar purpose, clams should be made of an alloy consisting of nine and a half parts of lead to one part of antimony.

FIG. 23.



The fitter and erecter will also require a scribing-block, which consists of a piece of metal jointed to a wooden block at one end, and having at the other a point; it is useful for marking centres, and for similar purposes.

In filing flat surfaces considerable practice is required, in order to avoid rounding them, in which consists the proper use of the file; and this is a matter in which nothing short of actual experience can be of any value, hence we shall not further dilate upon it.

In fitting round surfaces, such as a shaft to its bearings, a method somewhat similar to that used for truing plane surfaces is used; the shaft is turned and the bearings are bored as accurately as possible, after which some ruddle is rubbed upon the shaft, which is then worked in contact with the bearings. By this means the first points of contact are indicated, which are scraped down, and the process repeated until a sufficient degree of accuracy is attained.

In conclusion of these brief remarks upon manipulation, we may observe that in erecting machinery it is very necessary to have marks upon various parts in line with each other, in order to supply a means of determining whether any settlement or other derangement occurs subsequently.

CHAPTER VII.

ON THE PHYSICAL BASIS OF THE STEAM-ENGINE.*

In the present chapter we purpose to treat of the physical basis of the steam-engine, or in other words to examine the physical force upon which the action of the steam-engine depends, this force being heat.

With regard to the theory of heat, we cannot prove, certainly, in what heat consists, but it seems highly probable that it consists in motion of the atoms of which various bodies are composed. The ordinary effects of heat, such as expansion, contraction, liquefaction, and volatilization, are too well known to require any account at our hands, but we have yet to explain the circumstances under which these phenomena take place.

We must first mention the manner in which heat is conveyed from place to place. This may occur in three different ways—by radiation, by conduction, and by convection. By the first method we understand the heat to be propagated through gaseous matter; thus, if we hold our hand in the neighbourhood of a heated body we experience a sensation of warmth, the heat being radiated, as it is termed, through the air and communicated to the hand. The term conduction signifies the passage of heat through a solid body; thus if we place the end of a bar of metal in a furnace, keeping hold of the other end, we shall, after a short space of time, find that the heat has passed along the bar and is communicated to the hand. Let us now compare these processes of radiation and conduction in order to determine in what relation they stand to each other. If we accept the dynamic theory of heat, the following explanation will hold good.

* See Preface.

In the case of radiation in the example first mentioned, the atoms of which the heated body consists are moving within a certain limited sphere with an abnormal velocity, the sphere being increased according to the velocity with which they move, thus creating expansion; these atoms communicate motion to the neighbouring atoms of the circumambient air, which communicate their motion to other atoms of air, until the hand is reached. In the second example, the movement of the heated particles in the furnace is communicated to the nearest atoms of the bar of iron, from these to the next, and so on to the further extremity. These two examples differ only in the medium through which the heat is propagated—in the one case it is gaseous, and in the other it is solid, but in both cases the method of propagation appears similar. A portion of the heat is, however, carried off by the heated particles of air by the method of convection which we will now proceed to describe.

Let us suppose that we apply heat to a liquid, say water, we shall find that the heated particles will rise to the surface, being replaced by cooler ones—thus the heat is conveyed away, the heated particles passing away from the source of heat. A similar result occurs when gases are heated, an upward current being created. The motion of the particles away from the source of heat in the case of convection, is easy of explanation according to the dynamic theory. We may suppose that the atoms nearest the source of heat, when their temperature is raised, revolve in their spheres with increased rapidity, at the same time increasing the range of their spheres of rotation; thus, a fewer number of atoms will be contained in a given bulk at any given temperature, than will be contained in the same bulk at a lower temperature; hence the specific gravity of the heated liquid will be less than that of the cool liquid, wherefore the former will rise to the surface of the latter with a velocity proportional to the difference of temperature, thus producing the phenomenon of convection.

We may next speak of the so-called latent heat, a term which we consider as tending to lead to erroneous conclusions.

If we evaporate, say one ounce of water, and cause the whole of the resulting one ounce of steam to pass into cold water, we shall find that it is capable of raising five or six ounces of water to the

boiling point. At first sight this appears somewhat inexplicable, for we have one ounce of water raised to a temperature of 212°, and evaporated from that temperature, yielding one ounce of steam also at 212°, yet when this one ounce of steam is condensed, the heat contained in it is found capable of raising five or six ounces of water at a normal temperature to the boiling point, 212°; thus the steam has yielded in condensation about 1000° of temperature beyond that indicated by the thermometer. That the steam contained that heat was certain, and also that its presence could not be determined in a direct manner, and at the same time the duty done by such heat did not appear evident to the discoverer of the fact; hence, this 1000° of heat being hidden as it were in the steam, was called latent heat. It appears, however, that this heat is absorbed in changing the physical condition of the aqueous particles, being recovered when those particles are restored to their original condition.

It is also observed that whenever a body is expanded, heat disappears, or is absorbed by that body; and whenever a body is condensed, heat is evolved. And the converse also holds good; whenever heat is evolved condensation takes place, and whenever heat is absorbed expansion takes place. As an example of the first case, let us suppose a vessel to be filled with compressed air or steam, and allow this air or steam to issue through an aperture, then as it passes into the atmosphere it will be relieved from pressure, and will therefore expand, and upon holding the hand in the current of air, a cooling influence will be felt, the air in its expansion absorbing heat from the hand; the same will take place in the case of the jet of steam, which is more curious, because the steam exists at a much higher temperature than the air. This result, viz., the cooling influence of a jet of steam, is not obtained unless steam of a high pressure be used.

With regard to the evolution of heat under the case of condensation, we might quote many instances as examples; the condensation of steam is, however, sufficient for our purpose.

We may quote one example in support of the statement that wherever heat is evolved condensation takes place. This examination consists in the combustion of a jet of hydrogen gas in an atmosphere of oxygen; in this case a very great degree of heat is evolved, as is observed in the case of the oxy-hydrogen blow-

pipe, and a very great degree of condensation occurs; the amount may be imagined from the following approximate figures: to produce one cubic inch of water, nine hundred cubic inches of oxygen and eighteen hundred cubic inches of hydrogen will be required; thus a bulk of two thousand seven hundred cubic inches of gas is condensed into one cubic inch of water.

With regard to the absorption of heat occurring in conjunction with the expansion of bodies, we may refer to volatilization, which never takes place without a certain quantity of heat being absorbed, over and above that which is indicated by the thermometer.

We will next proceed to speak of what is termed specific heat. We may illustrate the meaning of this term most clearly by taking an example. Let us suppose that a certain quantity of hydrogen gas must be burnt to raise a pound of water 10°, then the combustion of the same quantity of hydrogen will raise eight pounds of iron 10°; we therefore say, that the specific heat of iron is 0·125 or $\frac{1}{8}$, if that of water is called 1 or unity.

From researches on heat, Petit and Dulong have deduced a law that the specific heat is the same for the atoms of all simple bodies, and this law is to a certain extent borne out by experiment.

We will now pass on to the transformation of heat into work or motion.

Heat and motion being mutually transformable into each other, it would appear that some constant ratio should exist between the quantity of heat and the work effected by it, or between the amount of work required to evolve a certain amount of heat and the heat evolved by such work; or in other words, that some mechanical equivalent to heat should exist. It is perhaps necessary here to mention what is meant by the term work, in its real sense; it is a force exerted through a space, and the intensity of the force, multiplied by the space through which it acts, is equal to the work done; and in this consists the difference between dynamic and static force, for the latter is a force at rest, or a pressure which is balanced by some other equivalent pressure, or by a number of pressures, of which the resultant is equivalent to it; but in the case of dynamic force the pressure is not so balanced, and in consequence, motion is produced.

The amount of work executed in any particular case we shall

state in foot-pounds, that is to say, we shall obtain our valuation of the work done by multiplying the force in pounds by the distance it passes through in feet—thus, if a force or weight equal to 30 pounds is caused to act through a distance of 12 ft., the work done will amount to 360 ft.-lbs.; also, if a force equal to 60 pounds is caused to act through a distance of 6 ft., we shall also obtain an amount of work equal to 360 ft.-lbs. We will now return to the mechanical equivalent of heat. Dr. Joule some time since made some careful experiments in order to determine the mechanical equivalent of heat, and the conclusion at which he arrived was that 772 ft.-lbs. are equivalent to that quantity of heat which is requisite to raise one pound of water 1° Fahrenheit, this quantity of heat being adopted as the unit or measure, in the same way as one inch is considered the measure of length, or one cubic inch is considered a measure of volume.

772 ft.-lbs. is, then, the quantity of mechanical work which we might expect to gain for every equivalent of heat, but our machinery is so imperfect that we do not realize this amount.

The method by means of which we make available to our requirements the dynamic force of heat, usually consists in the employment of the elastic or expansive force of some gas or vapour which has previously been produced in, or compressed into, a space less than that which it would occupy at a normal pressure. When steam is used, the requisite pressure is obtained by generating steam from water contained in a close vessel, such steam accumulating until the required tension is obtained: and the amount of steam generated will be found to exceed the bulk of water evaporated to produce it in the ratio of about seventeen hundred volumes for one at the ordinary atmospheric pressure. At twice this pressure the volume will be reduced to about half; at four times the pressure to nearly a quarter; and so forth.

If we have steam of a pressure of four atmospheres acting beneath a piston fitted in a cylinder, so that it can rise or fall, air and steam-tight, the top of the cylinder being open, then it is evident that the pressure beneath the piston will be four times as great as that above it, wherefore the piston will rise with a force equivalent to three atmospheres. The pressure of the

atmosphere is about 14·7 lbs. per square inch; but it may be taken in round figures at 15 lbs. per square inch.

It is in this difference between the pressures on the two sides of a piston made as nearly as possible air and steam-tight, that the mechanical principle common to all steam-engines consists.

There are two ways of working the steam-engine, expansively and non-expansively; and the engines are divided into two classes, condensing and non-condensing. In the former a vacuum is made on that side of the piston opposite to the steam side, by condensing the steam which previously occupied that space; whereas in the non-condensing engines the steam acts on one side of the piston, and the atmosphere on the other.

We will now speak of the two ways of working engines. By the first method, the non-expansive steam of the full pressure is admitted during the whole of the stroke of the piston,—that is to say, during the time of its passage from one end of the cylinder to the other. Whereas by the second method the steam is shut off when a part only of the stroke is performed, the remainder being executed by the expansion of the steam already admitted to the cylinder.

It is generally held that the expansive method of working is by far the most economical; but experiments have recently been performed by Stimers, Isherwood, and others upon an American vessel, the results of these experiments being in favour of the non-expansive system of working. It is, however, necessary to examine with care these experiments, in order to determine whether they afford really a sound proof of the inefficiency of the expansive mode of working. We find that in some cases the quantity of steam required was more when expansion in a high degree was employed, than when a low rate of expansion was used; thus when the steam was cut off at $\frac{1}{3}$ of the stroke, the consumption was 32 lbs. of steam per horse-power per hour; but for $\frac{7}{10}$ it was 33 lbs., and for $\frac{3}{10}$ 34 lbs. These are not exactly the quantities used, the decimals having been omitted; but they are sufficiently accurate for our purpose. This, however, only leads us to conclude that under the circumstances a moderate degree of expansion was found more economical than an extreme degree of expansion, which is not very easily accounted for, the

following calculation appearing to show that the higher the degree of expansion employed, the greater should be the economy obtained.*

Let us suppose that we have a steam-cylinder fitted with a piston, the area of which is 100 square inches, and let us have steam at a pressure of 60 lbs. to work with; suppose we allow the full pressure of the steam to act through half the stroke, the entire stroke being 2 ft., then the units of work executed during this half stroke will be the area of the piston, multiplied by the pressure per square inch, multiplied by the space passed through, which will be equal to 6000 ft.-lbs. Let us suppose the steam to be now cut off, then the steam in the cylinder will expand to the end of the stroke; being reduced to about half its normal pressure, and occupying twice its original bulk, the effective work being equal to the mean pressure on the piston during the half stroke: multiplied by the area of the piston and the distance passed through, the mean pressure will be rather less than half the sum of the pressures at the moment of cut off and at the termination of the stroke; this sum will be 90 lbs. Let us call the mean pressure 40 lbs., then the amount of work executed by the expansion of the steam will be 4000 ft.-lbs., about $\frac{2}{3}$ of that effected by the full pressure steam acting through the same space. The amount of work executed by one cylinder full of steam cut off at half stroke will be 20,000 ft.-lbs. If we use the steam at full pressure throughout the stroke, the amount of work executed by one cylinder full should be 12,000 ft.-lbs., $\frac{3}{5}$ of that executed by the same quantity of steam working at the above degree of expansion. It also further appears that all work done after the steam is cut off, is so much actual gain, as, if the steam were allowed to escape at full pressure, the work capable of being executed by its expansion would, of course, be lost. How, then, are we to account for a loss of economy when a high degree of expansion is used? Let us examine more closely into the conditions of the experiments quoted above, in order to see whether we cannot account for this loss. We find that the steam-pressure

* The manner in which the experiments are reported prevents our examining them thoroughly; also several experiments were not reported at all, and the same furnace was used at different rates of firing.

employed was certainly low, commencing with about 34 lbs. per square inch, and in extreme cases being expanded down to a pressure of 5·9 lbs. per square inch, in which case the temperature of the steam would be reduced from 279° down to about 229°; this reduction of temperature would of course cool the surrounding metal, which, in its turn, will abstract heat from the steam admitted to the cylinder at the next stroke, thereby causing a loss, this loss varying in proportion to the difference of temperature of the steam entering and leaving the cylinder. By using steam of a higher pressure in the same cylinder, the proportionate loss will not be so great, for although the loss expressed in degrees will be greater in proportion, the quantity of steam in the cylinder will also be greater; this point may, however, be more readily explained by an example. If steam be expanded from 30 lbs. pressure to 5 lbs. pressure, there is a loss of temperature of 48°. The number of units of heat abstracted from the metal will of course be proportional to this quantity, and the quantity of heat which the cool metal will absorb from the hot steam will also be proportional to the same quantity. If we expand steam at 60 lbs. down to 10 lbs., the loss of heat will be 67°, and the quantity abstracted from the hot steam at the next stroke will be proportional to this; but the quantity of metal has remained constant, whereas the weight of the steam is doubled: hence, to heat the metal 48°, steam at 30 lbs. pressure will have to yield 11 units of heat, whereas to heat the metal 67°, steam at a pressure of 60 lbs. per square inch would only have to lose 7 units. These considerations tend to show that the experiments give results which are reliable only under the circumstances under which they are conducted, and that steam of a higher pressure or engines differently constructed will give different results.

Some well-conducted experiments on the relations of heat to steam and mechanical work are now very much wanted, and it appears to us that these experiments should be performed with apparatus of very accurate construction, admitting of a great variety of pressures, and also allowing of variations in the general circumstances, in order that the quantity of heat lost by radiation and conduction may be estimated.

We may here remark upon the use of other gases besides steam to propel thermo-dynamic engines. The most important of these applications consists in the employment of atmospheric air, and the air or caloric engines appear in many respects to have the advantage over steam-engines: the principle of working is of course similar, that is to say, the air is expanded by heat in order to obtain pressure.

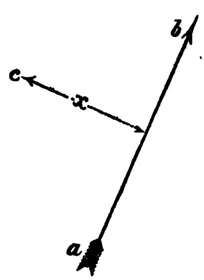
Engines propelled by ether have also been proposed, but we are not aware that they have been found practically useful. We would in concluding this chapter recommend our readers to examine C. W. Williams's theory of the evaporation of water; which we have refrained from discussing in these pages, as it is as yet not established, although there are many points of importance which may be decided without very great difficulty.

CHAPTER VIII.

ON THE PRINCIPLES OF MECHANICAL CONSTRUCTION.

We will now give a brief account of mechanics as applied to the construction of machinery, commencing with an account of the means of concentrating power. We will take as an example the ordinary lever. It will first be necessary to consider the manner in which a force acts round a centre. Let us suppose a force of 10 lbs. to act perpendicularly on one end of a bar, of which the other end is carried upon a centre, then the revolving force upon that centre will be proportional to the intensity of the weight or force, and to its distance from the centre. Let the bar be 6 feet long, then the relative intensity of the revolving force may be represented by 60 ft.-lbs. This revolving force is called a moment. We may find an equivalent moment by using a weight of 6 lbs. and a 10 ft. bar, for the moment in this case will also be 60 ft.-lbs. The general rule to find the moment of any given force about any given point will be, multiply the intensity of the force by its distance from the point measured perpendicularly to the direction of the force. In Fig. 24 we illustrate the manner in which this distance is measured. A force w acts in the direction $a\,b$; it is required to find its moment about the point c; from c let fall a perpendicular upon $a\ b$, and call the length of this perpendicular x, then will the moment of the weight about c

FIG. 24.



$$= wx.$$

From the above remarks it appears that any two moments will be equal when the distances of the weights producing them from the centres to which they are referred, vary inversely as the

weights. Suppose this condition to be fulfilled, and let the moments act about the same centre, but in opposite directions; then will a condition of equilibrium be attained, and in this balance of moments it is that the principle of the lever consists.

Let us suppose that we have an ordinary bar supported at one third of its length upon a pin or gudgeon, about which it is free to revolve, the weight of the bar being at present neglected, and let the length of the bar be 9 ft., then, on one side of the centre, pin, or fulcrum, as it is termed, there will be a length of 6 ft., and on the other a length of 3 ft.; let a weight equal to 500 lbs. be attached to the shorter end, it is required to find the weight which must be attached to the longer end, in order to balance this weight. The weights and their distances must vary inversely as each other; hence we may solve this question by proportion, thus—

$$6 : 3 :: 500 : 250.$$

250 lbs. will therefore be the weight required. We may give as the general rule for solving similar questions the following. To find the weight which, attached to one arm of a given lever, will balance a known weight attached to the other arm, multiply the weight by the length of the arm supporting it, and divide the product by the length of the other arm, the quotient will be the quantity required. Thus in the above case we have—

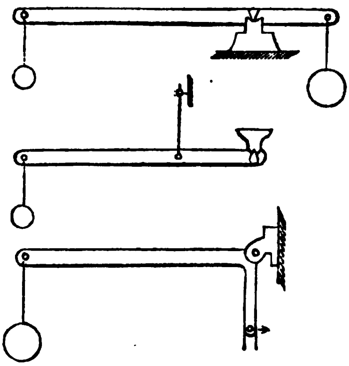
$$500 \times \tfrac{3}{6} = 250.$$

This rule will apply to every kind of lever, care being taken to observe the conditions under which it acts; its principle, however, is the same whether the arms be in a straight line with each other, or whether they be parallel or contain an angle, and if the length of the arms remains constant, the same forces will maintain equilibrium. Various forms of levers are shown, Fig. 25, but the same length of arms is preserved in every case. We may here observe that the proportions between the weights and arms refer to relative quantities, and not to absolute; thus a lever having arms 3 ft. and 6 ft. long will have the same value as one with arms 4 ft. and 8 ft. long, for the proportion of the arms is the same in both cases, as shown by the following equation—

$$\tfrac{6}{3} = 2 = \tfrac{8}{4}$$

Let us now compare the work performed when the arms move about the fulcrum in the case of the lever mentioned above. Let

Fig. 25.



the long arm move through 1 ft., then the amount of work executed will be

$$250 \times 1 = 250 \text{ ft.-lbs.}$$

Let us now examine the amount of work executed at the same time at the other end of the lever. We must first find the space through which the end of the short arm will move, whilst that of the long arm moves through 1 ft. The ends of the arms describe circles about the fulcrum; hence, in moving through the space mentioned above, a part of the circumference of a circle will be described, and the distance passed through will vary as the length of the arms which are the radii of the circular arcs; hence, the end of the short arm, which carries the 500 lb. weight, will move through half the space of the long arm, or through $\frac{1}{2}$ ft., the lengths of the arms being 6 ft. and 3 ft., and the amount of work performed at the extremity of the short arm will be

$$500 \times \tfrac{1}{2} = 250 \text{ ft.-lbs.},$$

which is equal to that performed at the end of the long arm.

From the above observations, we find that by means of a lever we may raise a given weight by a force equivalent to a much smaller weight, but at the expense of time; hence, in this case power is not gained, but a force expended during a certain time is concentrated to overcome a greater force, the static forces being

unequal, but the quantity of work done by them in a given time being equal.

We may now generalize the results of the investigation of the laws of the lever, in order to apply it to other machines for concentrating power in the following manner: In any machine let x represent the distance through which a given force is to be exerted, or through which an equivalent weight is to be lifted. Let w equal this weight or force; let y equal the distance through which the pressure required to raise it will move in the same time that w will move through x, w' being equal to the pressure, then the amount of work to be executed will be

$$= wx,$$

the work done by the motive power will be

$$= w'y.$$

These two quantities must be equal, or rather, to produce motion, one must preponderate by an infinitely small quantity, otherwise the apparatus will remain in equilibrio; the balancing forces may be found from the following equations:

$$wx = w'y$$

$$w' = w\frac{x}{y}$$

$$w = w'\frac{y}{x}$$

$$x = y\frac{w'}{w}$$

$$y = x\frac{w}{w'},$$

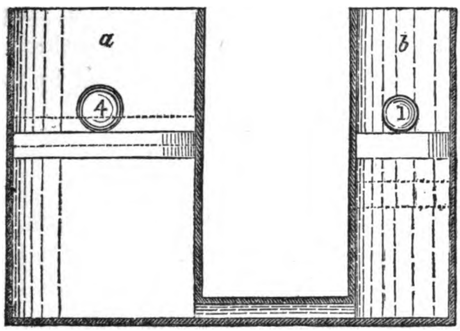
These equations will of course apply to simple or complicated machines, where an uniform resistance is overcome by an uniform force, x being the distance through which the point of resistance moves in a given time, and y the distance through which the point of application of the power moves in the same time.

The pulley and axle are evidently identical in their action with the two arms of a lever. The screw and inclined plane act differently, but the law given above will of course be applicable, the distances moved through being very easily found; thus, when a single threaded screw revolves once, any body which is

being raised by it passes through a distance equal to that between two threads of the screw measured from centre to centre.

We may now instance another means of concentrating power, viz., by hydraulic pressure. Let *a* and *b*, Fig. 26, represent two cylinders, each accurately fitted with a piston, as shown, the lower parts of the cylinders being filled with water, and communicating with each other by means of a pipe. Let the diameter

FIG. 26.



of *a* be twice that of *b*, then, because the areas of circles vary as the squares of their diameters, the area of the cylinder *a*, or of the piston contained by it, will be four times that of *b*. If we cause the piston in *b* to descend through a distance of, say 2 inches, a layer of water two inches thick will be displaced from the cylinder *b*, and forced into the cylinder *a*, where, however, it will spread out so as to cover four times the area which it did when in *b*; hence, the stratum, or layer, will have only one quarter the thickness, and the piston in *a* will rise through one quarter the distance that the piston in *b* is moved through; hence, a weight on the piston in *b* will balance a weight four times as great placed on the piston in *a*. This may be shown also by the following method of reasoning. If a pressure of *x* lbs. per square inch be imparted to the water contained in the two cylinders, the water will react in every direction, vertically, horizontally, and obliquely, with a force equal to 1 lb. per square inch; but the area of the large piston is four times that of the small, or contains four times as many square inches, therefore, as the total pressure on each piston is equal to the pressure per square inch,

multiplied by the number of square inches of surface of the piston, the water will exercise four times the pressure on the large piston that it does on the small, or, 1 lb. on the small piston will balance 4 lbs. on the large piston.

This principle is taken advantage of in the hydrostatic press, where a large force is exerted by means of a large piston working in a cylinder, into which water is forced by a pump of small diameter; the concentration of power obtained by these machines may be found by the following equations. Let f equal the force applied on the pump piston, d equal the diameter of the pump piston, and d' equal the diameter of the ram, or piston through which the force is to be applied, p equal pressure exerted by the ram, then

$$p = f\frac{d'^2}{d^2}$$

$$f = p\frac{d^2}{d'^2}$$

$$d = d'\sqrt{\frac{f}{p}}$$

$$d' = d\sqrt{\frac{p}{f}}$$

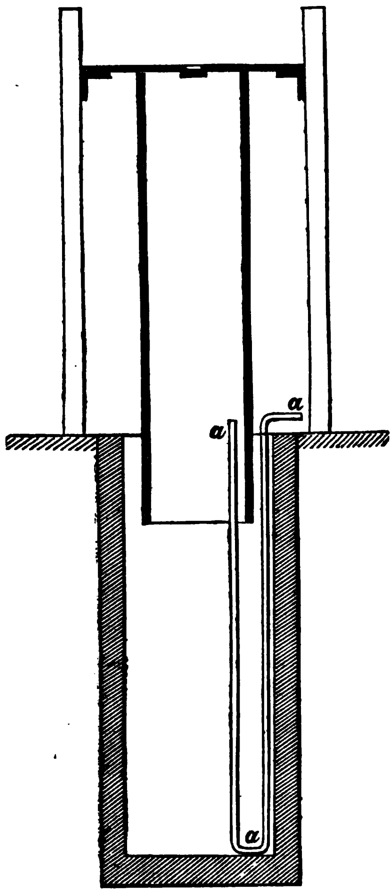
If the pump be worked by a brake, or lever, the force upon the pump-plunger in relation to that exerted upon the end of the lever must first be calculated.

There is another method of employing water-pressure by means of an apparatus which is termed a pneumatic lift; a section of it is shown in Fig. 27. This apparatus consists of a cylinder, closed at the upper end but open at the lower, working in a well, as shown. There is a valve in the cover, the use of which we shall presently indicate. There is an air-pipe connected with an air-pump, shown at *a a*: when air is forced through this pipe it displaces the water from the upper part of the cylinder, momentarily causing the water on the exterior of the cylinder to stand at a higher level than that on the interior, but being at a higher level, it will exert a greater pressure on the bottom of the well, which excess of pressure being transmitted upwards within the cylinder, will be passed through the air at the top of the cylinder, causing an upward pressure on the end of the same, whereby it will be raised to any desired height. Thus the cylinder is raised by a column of water, corresponding to the depth displaced within

the cylinder, the weight of such column being proportional to the pressure of the air by which it is displaced; the lifting power of this arrangement may be thus calculated:—

Let p equal the pressure at which the air is forced into the

FIG. 27.



cylinder in lbs. per square inch, and d the diameter of the cylinder, then the lifting force will be

$$= \cdot 7854 . p . d^2$$

The concentration of power obtained by this machine may be calculated by the formula given for the hydrostatic press, the

only difference being that in the latter water is the medium through which the pressure is transmitted, whereas in the pneumatic lift the pressure is transmitted through air.

When it is required to lower the lift, after it has been raised to any required height, it is only necessary to open the valve mentioned above, when the air will escape, and the lift will sink by its own weight.

It is evident that the same principle might be applied with any medium through which the pressure may be transmitted.

We must now proceed to speak of the action of those tools which produce impact or blows, such as the hammer, the hatchet, &c.; in this case the force applied is equivalent to the work accumulated in the tool producing the impact, such work being equal to the weight multiplied by the distance through which it passes. It is desirable here to offer a few remarks upon accumulated work. If a body whose weight is w, falls through a distance equal to h, the work done will be

$$= w\,h;$$

and the velocity which the body will have attained after falling through this distance, being equal to v, we shall have

$$v \text{ varies as } \sqrt{h}.$$

The reasoning from which this proportion is obtained being as follows :—

Let t equal the time of fall in seconds, g equal $32\frac{1}{6}$ ft., the velocity which a body will have acquired after falling the second. If a body falls freely through space, the attraction of gravitation will constantly act upon it, adding a velocity equal to g every second, therefore the velocity of the body will vary as the time of falling, or

$$v \text{ varies as } t.$$

Let us now examine the relation between the time and distance fallen through. It is evident that in the first second, the body having started with no velocity, and attained at the end of the second a velocity equal 32·1695 ft., the mean velocity will be 16·0837 ft. per second, and through this space the body will fall in the first second, at the end of which time it will have acquired a velocity sufficient to carry it through 32·1695 ft.

in the next second; but during that time the force of gravity continuing to act on it, it will receive the same increment of velocity as in the first second, and the total space passed through will be 48·25 ft. Following this reasoning further, we arrive at results embodied in the following formulæ :—

$$h = \frac{1}{2} g t^2 = \frac{1}{2} t v = \frac{v^2}{2g}$$

$$v = g t = \frac{2h}{t} = \sqrt{2gh}$$

$$t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}}$$

$$g = \frac{v}{t} = \frac{v^2}{2h} = \frac{2h}{t^2}$$

By substituting other values for g, these equations will hold good for other forces. If a body having the weight w falls through a height h, then will the work done

$$= wh,$$

as stated above, which by transformation becomes

$$wh = w \frac{gt^2}{2} = \frac{wg}{2} \frac{v^2}{g^2} = \frac{1}{2} \frac{w}{g} v^2$$

but $\frac{w}{g}$ is called the mass of the body, for as the mass multiplied by the attraction of gravitation is the weight, we have called m the mass.

$$m.g = w$$

$$\therefore m = \frac{w}{g}$$

hence substituting in the above equation, we have

$$wh = \frac{mv^2}{2}$$

This then represents the amount of work done by any given body in falling through a given space, and if it is unopposed in its passage, this work will constantly accumulate, being at any instant equal to the mass of the body multiplied by half the square of the velocity, and this is called accumulated work. If the body meet with any resistance, the work accumulated will be expended in overcoming that resistance, or in

partially overcoming it, the moving body being, in the latter case, in a state of rest.

It is work of this kind, viz., accumulated work, which is expended when a blow is struck by a hammer, and it matters not whether the hammer falls by its own weight, or is impelled by any other force, the amount of accumulated work may be found whenever the ultimate velocity is found.

Let us work out an example by the above formula: let a body weighing 64·339 lbs. be falling with a velocity of 20 feet per second, it is required to find the accumulated work at this velocity. The mass of the body will be,

$$\frac{w}{g} = \frac{64{\cdot}339}{32{\cdot}1695} = 2;$$

hence the amount of work accumulated in the body will be

$$\frac{m\,v^2}{2} = 400 \text{ ft.-lbs.}$$

We will also calculate by the height which a body must fall through to acquire the above velocity. It will be

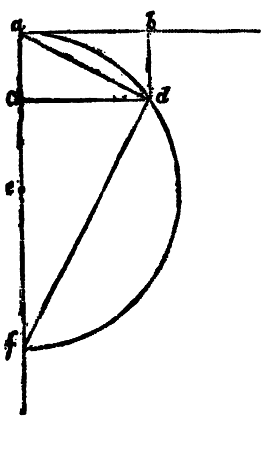
$$h = \tfrac{1}{2} \cdot \frac{v^2}{g} = \frac{400}{64{\cdot}339}$$

and the accumulated work will be

$$= w\,h = \frac{400}{64{\cdot}339} \times 64{\cdot}339 = 400 \text{ ft.-lbs.}$$

We will now pass on to consider the phenomena attendant upon rotatory motion. Let us suppose a body to be set in motion in the direction $a\ b$, Fig. 28; it is evident that in the absence of any other force, the body will move in the same direction continually; but it is possible to produce a curved motion by causing another force to act upon the body, this force acting in some other direction than $a\,b$. Let the body be attached to one end of a string $a\ e$, then will it be compelled to describe a circular arc about the point e; let us suppose that its velocity is such that it will pass from a to d in one second, then

FIG. 28.



we may call the chord $a\ d$ the velocity of the body, as when the arc is small, it will very nearly coincide with its chord. By referring to the diagram, it is evident that the string, by virtue of its tensile resistance, will in one second have drawn the body through the distance $b\ d$.

Let us now find the value of $b\ d$; it is equal to $a\ c$, $a\ b$, $c\ d$, being a rectangle.

Produce the radius $a\ e$ to meet the circumference of the circle in f, and join $f\ d$, then, because the angle $a\ d\ f$ is inscribed in a semicircle, therefore it is a right angle, and the angle $d\ a\ f$ is common to the two triangles $a\ c\ d$, $a\ f\ d$; hence these triangles are similar, the angle $a\ c\ d$ being a right angle, because $c\ d$ is parallel to $a\ b$, a tangent to the circle at the point where it is met by $f\ a$; therefore:

$$\frac{a\ c}{a\ d} = \frac{a\ d}{a\ f}$$

but $ad = v =$ velocity of body in ft. per second, and $a\ f = 2 =$ diameter of circle; therefore

$$\frac{a\ c}{v} = \frac{v}{2r}$$

$$a\ c = \frac{v^2}{d}$$

We must now, from this expression, find the value of the centrifugal force by proportion.

The weight of a body is the force tending to impart motion towards the centre of the earth, centrifugal force is the reaction of a body compelled to gyrate about a centre, tending to force it away from that centre; the measure of the first force, that of gravity, is $\frac{1}{2} g$; the measure of the second force is $\frac{v^2}{g}$. Let c represent centrifugal force, that is to say the tension of the string $a\ e$, which holds in the gyrating body as a table supports a body tending to fall, the string resisting the *weight* of centrifugal force, and the table resisting the *weight* of gravitating force; hence the following proportion holds good

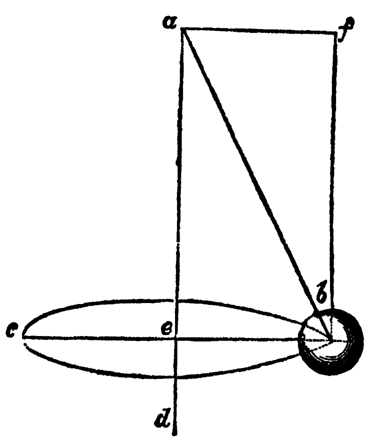
$$\tfrac{1}{2} g \ : \ \frac{v^2}{2v} \ :: \ w \ : \ c$$

$$\therefore\ c = \frac{w\ v^2}{r g}$$

From this equation, the centrifugal force may in any case be obtained when the body revolves in a circle, or in any other curve if its radius of curvature, at the instant when the velocity is given, be known. The method of finding the radius of the circle osculating any given mathematical curve, will be found in treatises devoted to that subject, and as the case seldom applies to the machinery we shall hereafter consider, we shall not further dilate upon it.

It is necessary now to examine the principle upon which the conical pendulum is constructed. Let *a b*, Fig. 29, represent a wire or string fixed by a pin at *a*, and carrying a heavy ball at *b*; let this ball *b* be revolving in an orbit, such as that shown by the dotted circle *b c*. From *a* let fall a perpendicular to the horizon, as shown at *a d*, the perpendicular passing through the centre of the circle *b c*, and forming the axis of the imaginary cone *a b c*, described by the revolution of the arm *a b*. From the centre of the ball *b*, let fall *b e* perpendicular to *a d*, complete the parallelogram *a e*, *b f*, we shall then have two forces acting on the ball *b*, tending to move it about *a* as the centre. The weight being *w*, it will produce a force whose moment about *a*

Fig. 29.



$$= w \times e\,b.$$

In the other direction, we have, if *c* equals the centrifugal force of the ball, a force whose moment is

$$= c \times e\,a.$$

If the ball is in equilibrium these two forces must balance, and therefore,

$$c \times e\,a = w \times e\,b.$$

Let $h = e\,a$ the height of the point of suspension above the plane

of gyration. Let $r =$ the radius of gyration $e\,b$, then will

$$c = \frac{w\,v^2}{r\,g}$$

$$\text{but } v = 3{\cdot}1416\,r \times 2n$$

where $n =$ the number of revolutions per second; but if $n =$ the number of revolutions per minute,

$$v^2 = \left\{\frac{3{\cdot}1416{\cdot}\,r \times 2\,n}{60}\right\}^2$$

By replacing

$$h = \frac{g\,r^2}{v^2} = \frac{35225}{n^2} \text{ inches}$$

nearly. This formula may also be written by an obvious transformation

$$h = \left\{\frac{187.7}{n}\right\}^2$$

and from this we derive

$$n = \frac{187{\cdot}7}{\sqrt{h}}$$

Another class of rotatory motion with which we shall subsequently meet, consists in the movement of a fly-wheel employed to prevent any great variation of velocity, which might occur by reason of the varying force exerted upon the shaft of the machine to which it is applied. The theory of the fly-wheel is somewhat complicated, and therefore unfit for insertion in the present treatise. In many instances rules have been given of a simple character, but incorrect, and therefore useless.

We will now conclude this account of statics and dynamics, which will be found sufficient for our subsequent requirements.

CHAPTER IX.

ON THE GENERAL ARRANGEMENT OF THE STEAM-ENGINE.

Let us now examine the means necessary to be taken in order to convert the heat contained by the steam, with which the steam-engine is supplied, into dynamic force, in a form suitable to our requirements.

There are three kinds of engines, which must be considered separately: in the first class the piston admits only of rectilineal motion; while in the second class the piston revolves, either continuously or with a reciprocating motion, about an axis or centre; and in the third class the piston moves in such a manner that its periphery describes a zone of a sphere. In engines of the first class the piston is impelled alternately in each direction by the difference between the pressures existing on the opposite sides of the same; thus in a condensing engine, if p represent the pressure of steam, and P the vacuum, both being stated in pounds per square inch, then, taking 14·7 lbs. per square inch as the mean pressure of the atmosphere, we shall have for the effective force f per square inch on the steam side of the piston—

$$\begin{aligned} f &= p + 14{\cdot}7 - \left\{ 14{\cdot}7 - \mathrm{P} \right\} \\ &= p + \mathrm{P}. \end{aligned}$$

Let, for example, $p = 20$ lbs. per square inch, and $P = 11$ lbs. per square inch, then will the effective pressure per square inch be,

$$f = 20 + 11 = 31 \text{ lbs. per square inch.}$$

In a non-condensing engine the vacuum becomes nothing, hence in that case the steam-pressure is the effective pressure. The power of any engine is very easily calculated—it is repre-

sented by the amount of work done in a given time, and is usually referred to the power of a horse, which was determined by Watt to be

$$= 33{,}000 \text{ ft.-lbs. per minute.}$$

Hence the power of any given engine will be as follows :—let p = effective pressure of steam, a = area of piston in inches, d = diameter of piston, v = space passed through by piston in feet, t = time occupied by the piston in passing through the space v in minutes; HP = horse-power, l = length of crank, n = number of revolutions performed while the piston passes through the space v; then

$$HP = \frac{p\,.\,a\,.\,v}{33000\,.\,t}$$

but

$$a = 0{\cdot}7854 d^2$$
$$v = 4\,.\,n\,.\,l$$

therefore

$$HP = \frac{p.\,0{\cdot}7854\,d^2.\,4.\,n\,l}{33000\,t}$$
$$= \frac{p.\,d^2.\,n.\,l}{10504\,t} \text{ nearly.}$$

Let it be required to calculate the power of an engine having one cylinder 20 inches in diameter, with a crank 1 foot 6 inches in length, or 1·5 feet; let the effective pressure be 25 lbs. per square inch, and the number of revolutions of the crank thirty-five in one minute, then

$$HP = \frac{25 \times 400 \times 35 \times 1{\cdot}5}{10504 \times 1} = 49{\cdot}98,$$

say 50 horse-power.

There are two methods of calculating the horse-power for condensing engines, the results being called the indicated horse-power and the nominal horse-power. To calculate the latter, it will be necessary to proceed as follows :—

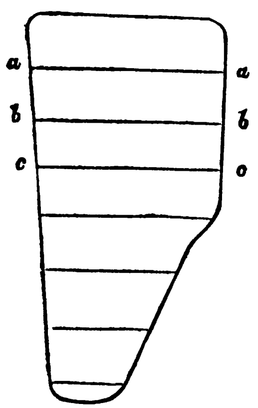
Take for the effective pressure 7 lbs. per square inch, and for the speed 220 ft. per minute; let the area of the piston be 1000 in., then, by the first rule,

$$HP = \frac{7 \times 1000 \times 220}{33000 \times 1} = 46{\cdot}66.$$

For the actual or indicated power, we must follow a different course, taking for effective pressure the mean effective pressure; to find which it is necessary to take a diagram from the engine, which is done thus:—a piston is accurately fitted to a small cylinder, screwed in the top or bottom of the main cylinder; the piston is retained at mid-stroke by a spiral spring, and when pressure occurs in excess beneath the piston, the latter rises, and *vice versâ;* to the piston-rod is attached a pencil, which, as the little piston rises and falls, describes a line straight or curved, on a piece of paper, which moves backward and forward with the piston in the main steam-cylinder.

From the figure produced by the indicator the pressure of the steam in the cylinder at any point in the stroke may be found, the mean pressure may be taken with sufficient accuracy for practical purposes as follows:—draw a number of ordinates *a a*, *b b*, &c., upon the indicator card, measure the ordinates on the scale of pressures, and divide the sum of the pressures so found by the number of ordinates taken.

Fig. 30.



A rule, very frequently used for condensing marine engines, is constructed on the assumption of 7 lbs. pressure of steam per square inch, with a speed of 200 ft. per minute; the formula for nominal horse-power will then become:

$$HP = \frac{p.\ a.\ v}{33000f} = \frac{7 \times 0{\cdot}7854 d^2 \times 200.}{33000}$$

$$= \frac{d^2}{30} \text{ nearly.}$$

The former formula would be:

$$HP = \frac{d^2}{24}$$

It will immediately be seen that rules for nominal horse-power

are little better than empirical, being merely useful in a commercial sense, and rather as a standard of value than power.

The following formulæ will be found sufficiently accurate for practical purposes, and useful to those who are engaged in designing steam-engines :—

$$HP = \frac{p.\ n.\ l.\ d^2}{10500}$$

$$p = \frac{10500\ HP}{n.\ l.\ d^2}$$

$$n = \frac{10500\ HP}{p.\ l.\ d^2}$$

$$l = \frac{10500\ HP}{p.\ n.\ d^2}$$

$$d = \frac{\sqrt{10500\ HP}}{p.\ n.\ l}$$

We will next speak of the power of those engines which are fitted with pistons revolving about an axis or centre, first taking the case of a piston revolving continuously in one direction, the piston being rectangular. Let r = the distance in inches from the centre of revolution to the nearest edge of the piston, r' = the distance from the centre to the furthest edge of the same, b = breadth of piston in inches, p = effective pressure of steam, n = number of revolutions per minute. Then —

$$HP = b\left\{ r'-r \right\} \cdot \frac{3{\cdot}1416}{12} \cdot \frac{r+r'}{2} \cdot \frac{n.\ p.}{33000}$$

because $b\left\{ r'-r \right\}$ = area of piston in inches,

and $\dfrac{3{\cdot}1416\left\{ r+r' \right\}}{24}$ = mean space passed through by the piston in one revolution.

By reduction :—

$$HP = \frac{n.\ p}{252100}\left\{ r'^2-r^2 \right\}.b$$

If the piston oscillates through a portion of a revolution, the formula must be modified thus :—

Let $\frac{1}{m}$ represent the fraction of a revolution through which the

piston oscillates, then the formula will be, n being equal to the number of oscillations per minute :—

$$HP = \frac{n.p}{252,100}\left\{r'^2 - r^2\right\}\frac{b}{m}$$

thus, if the piston vibrates in a semicircle—

$$HP = \frac{n.p.b.}{504,200}\left\{r'^2 - r^2\right\}$$

if it vibrates in a quadrant of a circle—

$$HP = \frac{n.p.b.}{1,008,400}\left\{r'^2 - r^2\right\}$$

We now have to consider the last kind of engine of which we spoke, viz., that in which the circumference of the piston describes a zone of a sphere; this is called the disc engine. The disc or piston is placed between two cones, united by the spherical zone described by the periphery of the piston, which in its motion reminds us of a disc, which having been caused to spin upon its edge is about to fall, when it performs gyrations about its rim; we shall in the present place insert an approximate rule whereby its power may be calculated. Let r = radius of the disc or piston, r' = radius of sphere upon which as a centre the disc gyrates, t = thickness of the edge of the spherical zone, or length of the steam-chamber, all in inches, then—

$$HP = \frac{3{\cdot}1416\ tn.\ p}{2 \times 3 \times 12 \times 33000 \times r}\left\{r^3 - r'^3\right\}$$

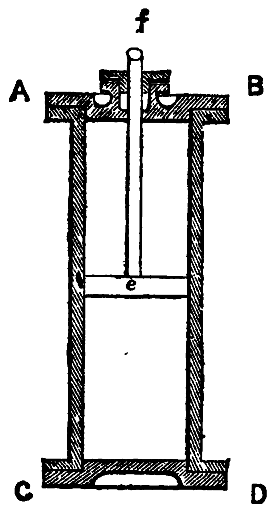
$$= \frac{t.\ n.\ p}{756,310r}\left\{r^3 - r'^3\right\}$$

We have now considered the arrangement of the steam-engine with regard to power, our next step will consist in examining the means of applying such power.

Let us commence with the first class of steam-engines. Here we have the work presented in the form of a pressure acting in a straight line, alternately in opposite directions. The piston is urged backwards and forwards from end to end of the cylinder by the steam pressure acting alternately upon each side of it. To this piston is attached a rod, which passing out at an air-tight

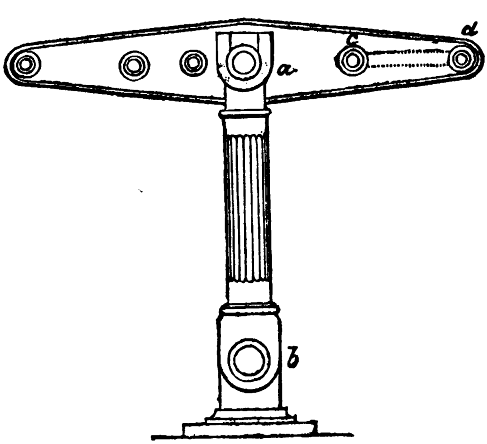
aperture in the cover of the cylinder, communicates the motion of the piston from within the cylinder to the external machinery; this arrangement is shown in Fig. 31, in which A B C D is the steam-cylinder, *e* the piston, and *ef* the piston-rod. In the first case, let the point of application of the power be required to move in a straight line, then the piston-rod may act directly upon the work, or it may operate through the intervention of a beam; but if this latter arrangement is employed, some means must be taken to enable the head of the piston-rod to move in a straight line, notwithstanding the curvilinear motion of the end of the beam or lever, for if this were neglected the piston-rod would be bent. The means of effecting the desired end are very numerous, but we shall here describe only those which have been found practically useful.

Fig. 31.



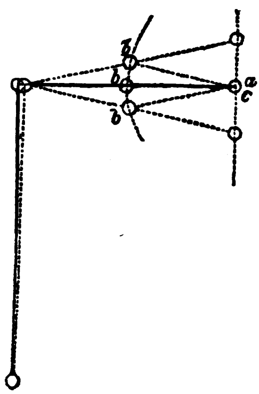
The simplest method consists of so forming the column *a b*, Fig. 32, which supports the bearings upon which the main beam

Fig. 32.



d, oscillates, that it may vibrate upon an axis placed at *b*, the lower extremity, whereby that end of the beam to which the piston-rod is attached, is enabled to adjust itself. The extremity of the beam is caused to move in a line very nearly straight by means of the link, *c d*, which is attached to the beam at *c* by a centre, and to a part of the framing at *d*, in the same vertical plane with the piston-rod. The manner in which this contrivance effects the desired end is sufficiently simple, as may be shown by the diagram, Fig. 33. Let the full lines represent the bars, constituting the parallel motion, as it is called, at mid-stroke, when they will be parallel to each other; then the dotted lines will represent their position after the stroke has been continued through a short distance, during which the deviation of the piston-rod head from a rectilineal movement, would be equal to the versine of the angle passed through by the bar *a b*, multiplied by the length of the bar, had the centre *b* been fixed; as it is, however, the centre *b* is carried at the extremity of the bar *b c*, which moves upon a fixed centre at *c*, and the deviation of the point *b* from rectilineal motion being in a contrary direction to the deviation mentioned above, compensates for it; by this contrivance it is not an absolutely straight motion that is obtained, but one very nearly approximating to it.

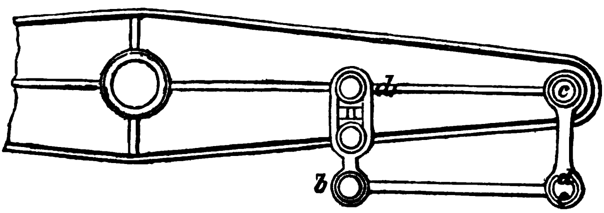
Fig. 33.



Under some circumstances it would, however, be unsatisfactory to use the above movement, which is most frequently applied to half-beam or grasshopper engines. As the vibration of so large a mass of the beam and the pillar supporting it, would in a machine of considerable dimensions give rise to serious inconvenience; an arrangement shown, Fig. 34, is, under these circumstances employed, and combines within itself the properties of two parallel motions, the first, which in its action is identical to that described above, corrects the deviation of the top of the piston-rod; it is formed by the bars *a b*, *b c*, which are attached by

parallel links to the main beam, as shown; at the centre, or near it, of the vertical link, *b d*, there also exists a point whose motion approximates nearly to a rectilineal movement; and the means

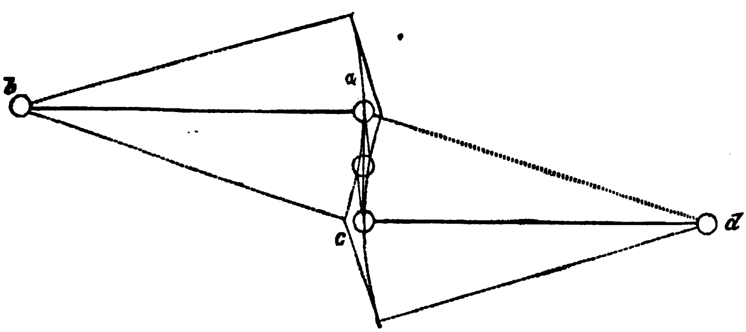
FIG. 34.



by which this is obtained we will describe by the assistance of another diagram, Fig. 35.

a b is one-half of the main beam, working upon a fixed centre at *b*; *c d* is a link of equal length working upon a fixed centre at *d*; the extremities of the two bars are connected by the link *a c*, the whole being so adjusted that at mid-stroke the angles *b a c*, *d a c*, are right angles; then by the oscillation of the arms *a b*

FIG. 35.

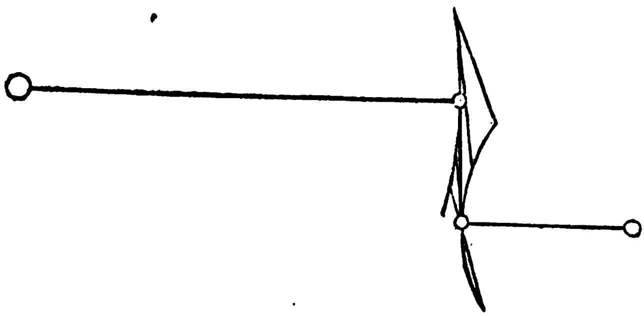


and *c d* the extremities of the link *a c* are caused to deviate in opposite directions. The dotted lines show the paths of various points in the link *a c*, which, it will be observed, approximate more nearly to a straight line as we approach the centre of the link.

If in the case of the motion last described the arms be not of equal length, then it is evident that that point of the link,

a c, which moves in a line most nearly approximating to a straight line, will not be in the centre of the link, but nearer the longest arm. A motion with unequal arms is shown, Fig. 36, the dotted

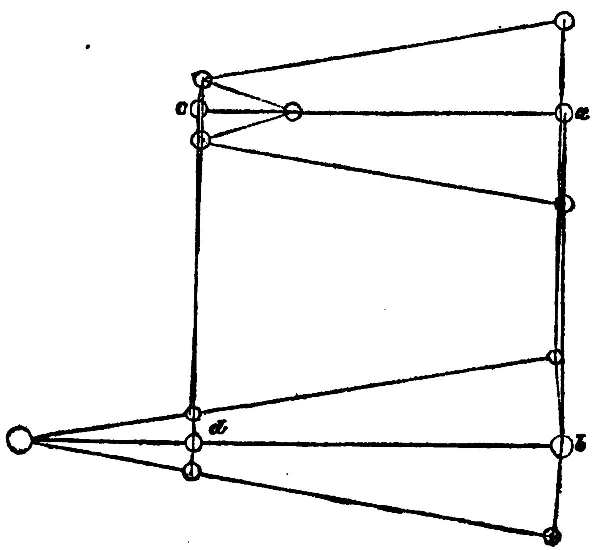
Fig. 36.



lines representing as before the paths of various points in the connecting link.

In marine engines an arrangement differing in form must be employed to attain the same end. A common form is shown in Fig. 37; *a* is the head of the piston-rod to which a cross-head is attached; from this cross-head arms, *a b*, run down to the beam

Fig. 37.



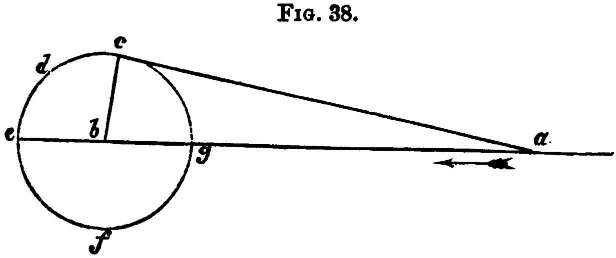
which is placed beneath, and arms, *a c*, run from the cross-head to a short arm, capable of moving upon a centre. Upon the same centre is fixed another arm, or the same may in some cases be used, from the extremities of which rods pass down to the beams beneath. The length of the short arms is adjusted in right proportion to correct the deviation, which might otherwise be caused by the angular motion of the beams. Another means of regulating the motion of the piston-rod consists in attaching to its upper extremity a cross-head, carrying blocks, which move between guides fixed parallel to the axis of the piston-rod. Other kinds of motions are also occasionally used, but they are principally derived from the foregoing, wherefore it is unnecessary to give a complete account of these movements.

If it be necessary that the rod attached to the other extremity of the beam should move rectilineally, then the same means may be employed to ensure rectilineal motion as were used to regulate the motion of the piston-rod.

It most frequently happens that the motion of machinery to be driven by steam-power is rotatory, when it will be necessary to adopt some contrivance for converting the reciprocating rectilineal motion of the piston into a rotatory motion. In order to effect this end, numerous arrangements have been devised, but none of them answer so well the purpose as does the crank, nor is any other form practically applied; we shall therefore describe only the means furnished by this contrivance, which deserves a very careful consideration.

Let *a*, Fig. 38, represent the head of the piston-rod, which

Fig. 38.



is guided so that it can only move in the direction of the straight line *a b*. Let *b c* be a crank capable of revolving about the point *b* as a centre, the extremity *c* describing the dotted circle. The

extremity of the piston-rod is connected with the extremity *c* of the crank by means of a connecting-rod, *a c*, the points of junction, *a* and *c*, being made by pins, about which the connecting-rod may move without restraint. If the point *a* be supposed to move forward in the direction of the arrow, the extremity *c* of the crank will describe an arc from *c* towards *d*, until it arrives at the point *e*, which is in the straight line with *a b*. Then it is evident that whichever direction the point *a* tends to move in, no motion can possibly be produced in *c*, as the force would act exactly at right angles to the direction in which the point *c* must be moved. If *c* be carried past this point, and a motion the reverse of the former be imparted to *a*, the extremity *c* of the crank will pass through the semi-circumference *e f g*, and upon arriving at the point *g* we shall find that this, like the point *e*, is a point of no motion. The means employed in practice to carry the crank past these points of no motion, technically called dead points, will be explained hereafter, our attention being at present confined to the action of the crank in regard to the alteration suffered by the force in its transmission through the same.

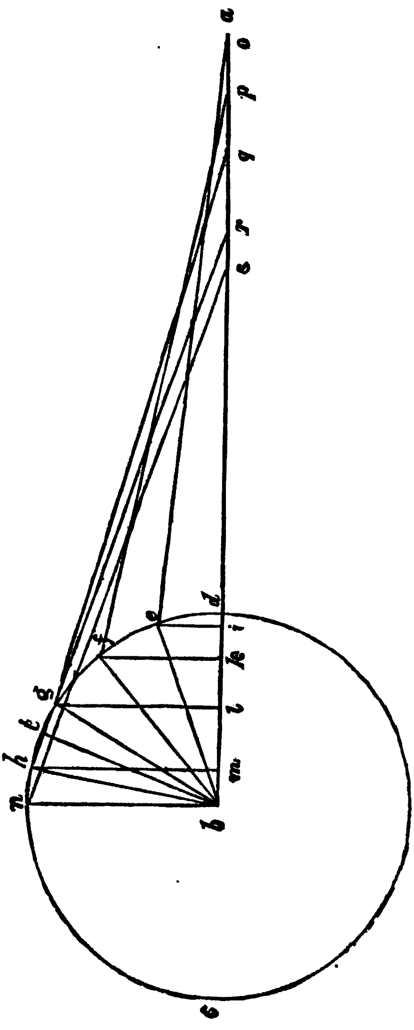
To illustrate the action of the crank another diagram will be serviceable. It is shown at figure 39: *a* is the head of the piston-rod, *b* the centre upon which the crank revolves, and *c d* the dead points; *a d* is the connecting-rod; the position is shown by the full lines when the crank is upon the dead point *d*. The dotted circle which represents the path of the extremity *d* of the crank *b d* is divided into eighteen parts in order that the variation of the force transmitted to the shaft, upon which the crank is fixed, at different parts of the stroke, may be examined. It will be sufficient for the present purpose to investigate the case for the points *e f g h* in the first quadrant of the circle; but it is desirable to include an extra point, *n b*, showing the position of the crank when at right angles to the straight line *a c*. In order to comprehend the variations undergone by the motive force applied at the point *e*, the case must be treated by the well-known principle of the parallelogram of forces.

The length of the connecting-rod being constant, we can find the position of the head of the piston-rod corresponding to each of the points *e f g*, &c., by marking off from those points upon

the line $a\ c$, distances $e\ o\ f\ p$, &c., each equal to the length of the connecting-rod.

The first step will consist in the resolution of the strain in the

Fig. 39.



direction of the connecting-rod, and in the other direction in which it acts, of which, however, no mention has yet been made. The directions in which the force will be resolved are

evidently the axis of the piston-rod, and at right angles to the same, the latter producing pressure upon the guide blocks and guides. Hence it may be concluded that in the case of any position, such, for instance, as that corresponding with the point *g*, the relative values of the forces will be represented by the sides of a right angle triangle, consisting of the length and position of the connecting-rod *g q*, the perpendicular let fall from the point *g* upon *a c*, this perpendicular being in the present case *g l*, and that part of the line *a c* which is contained between the extremity of the connecting-rod and the perpendicular mentioned above, in the present case *l q*.

Let P represent the total pressure on the piston, and therefore the total pressure acting in the direction *a c*; then the forces acting in the various directions will be as follows. The pressure on the guide-blocks will be

$$= P \frac{lg}{lq}$$

That on the connecting-rod will be

$$= P \frac{qg}{lq}$$

but *q g* is constant; call it = L, then the force upon the connecting-rod

$$= P \frac{L}{lq}$$

In order to find the moment of the last force, about the centre *b* produce the line *q g*, and from the point *b* let fall upon it the perpendicular *b t*, then will *b t* represent the distance at which the force acts, and the moment about *b* will be

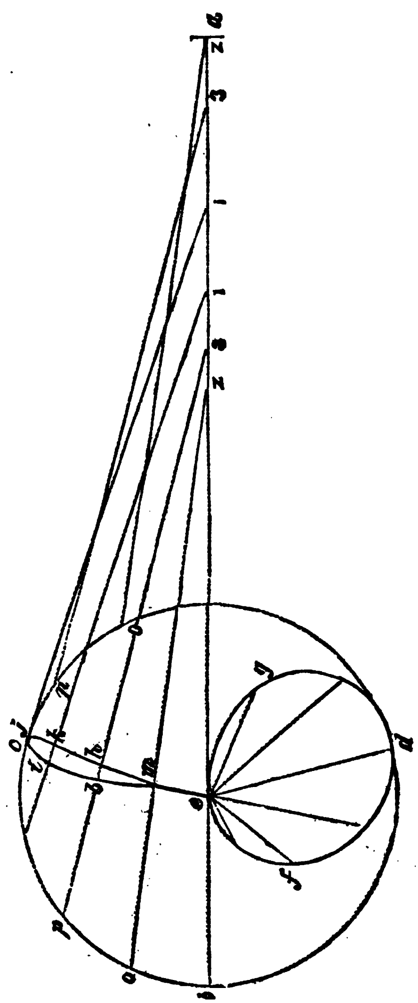
$$= P \frac{L}{lb} . bt$$

In a similar manner the moment of power may be found for the other points. The lower quadrant immediately beneath *b n d* will exhibit the same phases, the remaining quadrants being different. Having found a means of calculating the moment of pressure, it may be interesting to draw the curve through which the point *t* passes.

Let *a b*, Fig. 40, be the straight line in which the head of the

piston-rod moves. The change of force due to the position of the crank shall first be determined, the force on the connecting-rod being for the present supposed to be constant; then the

FIG. 40.

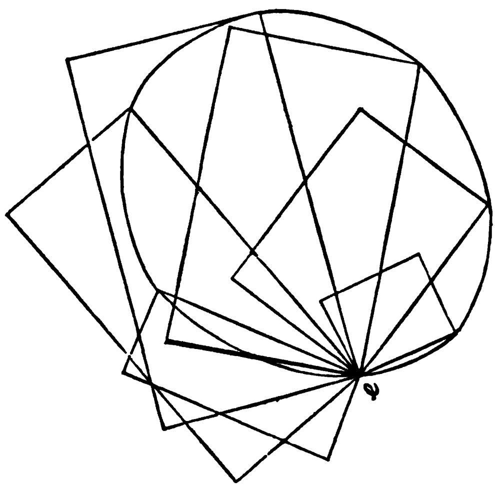


point upon which the perpendicular to the connecting-rod falls will at each point of intersection, there being fourteen intersections, pass through the points *l i j k h m* and *e*; and if

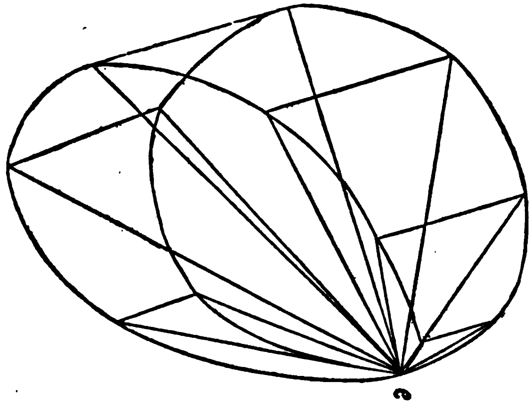
the lengths of these perpendiculars be laid off radially from the centre *e* along the axis of the crank for each position, we shall obtain the figure *e f g d*. The force on the connecting-rod is not, however, constant, but varies as the length of the perpendicular, divided by the horizontal distance between the extremities of the connecting-rod. It is worthy of note that at symmetrical divisions, as *oo pp*, the positions of the connecting-rod are parallel, and therefore the strain upon the connecting-rod at any point

FIG. 40 (*a*).

Z



Z′

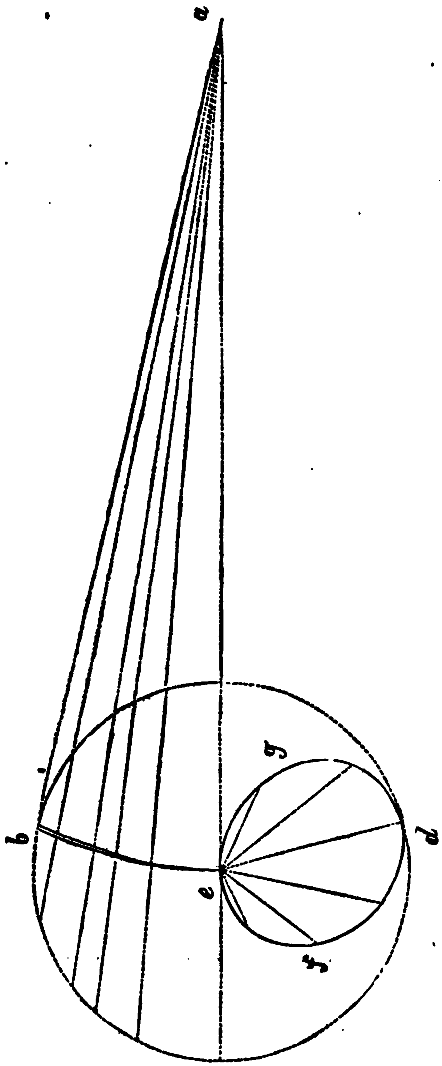


at a given distance from the axis of one side of a line at right angles to the same is equal to the strain upon it for a corresponding point on the other side of the said line. We may find the relative value of the moment actually acting upon the centre *e*, when the pressure in the direction *a b* is constant, for any position of the crank, by multiplying the length of the perpendicular by the relative pressure on the connecting-rod, the result being represented geometrically by an area or surface, which may be either a rectangle or a right-angled triangle. At Z is shown an enlarged view of the figure *e f g d*, the moments being represented by rectangles. It is evident that if triangles be taken instead of rectangles, these triangles being placed with their apices meeting at the centre *e*, the total sum for every position of the crank in the semicircle may be conceived to constitute a solid, bounded by three surfaces, of which two are plain and one curved. Such a solid is shown at Z′; then if any section of this solid be taken by a plane passing through the point *e*, the plane being perpendicular to the upper surface, we shall obtain a triangle representing the relative moment, about *e*, when the crank axis lies in that plane. It may be desirable to notice the effect of lengthening or shortening the connecting-rod. If a longer connecting-rod be used the perpendiculars for all positions on the nearest semicircle to the head of the piston-rod will be shortened, and those on the opposite semicircle will be lengthened, the result of which will be that the figure *e f g d* will more nearly approach a symmetrical form, approaching nearer in contour to the dotted circle shown as the length of the connecting-rod increases. Hence, the longer the connecting-rod, the more uniformly will the engine work; and the shorter the connecting-rod, the more irregular will its movements be. It is evident that the figure *e f g d* can never become perfectly symmetrical, as in that case the connecting-rod would be required to be infinitely long.

Before taking leave of the crank, it is desirable to mention the action of the crank under the oscillating engine. In this case, the cylinder is placed upon trunnions, the piston-rod head being jointed to the crank, the lateral movement of which is allowed for by the vibration of the cylinder. The pressure upon the crank, coming always direct from the piston, is uniform, hence the variations of

the length of the perpendiculars only need be considered. In Fig. 41 we show curves illustrating this variation. The point *a*

Fig. 41.



is the axis upon which the cylinder oscillates; *b e* is the curve described by the point upon which the perpendiculars fall for each

position of the crank, and *efdg* exhibits the variation of the ultimate moment of power about the centre *e* for one stroke. It is evident from these diagrams that the action of the oscillating engine is far more uniform than that of the fixed cylinder engine, as the solid, illustrative of the action of the crank in the former machine, will be of uniform thickness throughout.

When a beam engine is used to give a rotatory motion, the connecting-rod is attached to one end of the beam.

The pumps consist of cylinders, fitted with plungers, and their action will hereafter be described.

The slides by which the steam is admitted to the cylinder have a rectilineal movement, derived from the motion of the engine itself. In engines having rotatory motion, this rectilineal movement is obtained by means of an eccentric wheel fixed upon the main shaft, as shown, Fig. 42; its action is equivalent to that of the crank, and in fact the eccentric might be replaced by a crank, as shown by the dotted lines.

When an intermittent motion is required, a contrivance called a cam is made use of, which cam is of the form shown in Fig. 43.

Fig. 42.

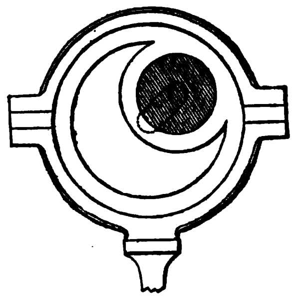
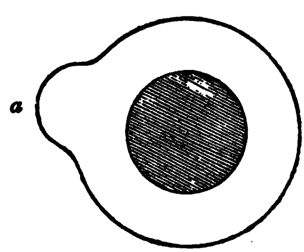


Fig. 43.



The camber *a* raises the end of the lever at every revolution, the end falling again as soon as the camber has passed it.

With regard to the rotatory engine there is little to be said, as the rotatory motion is immediately obtained. In the disc engine a piston-rod attached to the centre of the piston describes a cone, and its extremity, which describes a circle, is fitted to a crank. The last part of the steam-engine which will be mentioned here is common to all varieties of land engines; it is the

fly-wheel, which consists of a heavy wheel placed on the main shaft, to carry the crank over the dead points, and to act as a corrective to the variation of force on the shaft. Its action is this: at the point of maximum speed an extra quantity of work is accumulated in the fly-wheel, which is expended during the period of minimum force.

CHAPTER X.

GENERAL PRINCIPLES OF STEAM-BOILERS.

THE vessels in which water is evaporated in order to supply steam to steam-engines, are technically called boilers, and their forms are very varied. The first point to be considered is the power of a boiler; that is to say, to determine the quantity of water which the boiler will evaporate, the horse-power being considered equivalent to the evaporation of one cubic foot of water per hour. The quantity of fire and heating surface requisite to evaporate one cubic foot of water per hour, has at various times been determined; it was formerly taken at one square foot of fire surface, and nine horizontal feet, or one yard horizontal heating surface, sometimes also called water surface. But later experiments have shown that this is more than sufficient, 8·1 square feet per horse-power being all that is required. Vertical surface is considered only half as efficient as horizontal surface.

The rule for the nominal horse-power of a boiler may now be given. It is exceedingly simple. Let s equal the whole horizontal heating surface, plus half the vertical heating surface in square feet, then will the horse-power of the boiler be

$$H P = \frac{s}{8 \cdot 1}$$

When we have cylindrical surfaces to deal with, other rules will be found more convenient. If, for instance, the furnace is contained in a cylinder, so that the flame and hot air act on the upper half of the tube, then the horse-power to which the surface thus afforded is equivalent may be found from the formula

$$H P = \frac{l\,d}{5}$$

l and d being the length and diameter of the tube in feet.

Many boilers are now made in which the heating surface is furnished principally by small tubes, such boilers being known as multitubular boilers, and in calculating the power of these it will be inconvenient to take the diameter of the tubes in feet in consequence of their small size; hence, a rule must be found, for the diameter in inches. In this case, the heated air acts on the whole surface of each tube; hence, if n be the number of tubes, d the diameter in inches, and l the length in feet, the following rule will give the power:

$$HP = \frac{n\,l\,d}{30}$$

It may be advisable to consider the effect of size of the tubes, with regard to heating surface, it being taken for granted that a certain section is required for draught, which section is to be given by a number of tubes.

Let n equal the number of tubes, d the diameter of one tube in inches, a the total area of air passage in square inches; then the quantities may be found from the following equations, l being the length of tubes in feet:

$$a = 0{\cdot}7854\, d^2 n$$

but

$$HP = \frac{l\,d\,n}{30}$$

hence,

$$a = \frac{706\,\overline{HP}^2}{l^2 n}$$

From this formula it will be seen that the area varies as the square of the horse-power, and inversely as the number of tubes, and the square of the length; therefore, the smaller the tubes are made, the greater will be the heating surface in proportion to the area of the air-passage, and more heat will be taken up from the gases in their passage; wherefore we may conclude that it is desirable to make the tubes as small diameter as possible. The following formula may, in addition to those already given, be found useful:—

$$l = \frac{30\,HP}{d\,n}$$

$$n = \frac{30\,HP}{l\,d}$$

$$d = \frac{30\ H\ P}{l\ n}$$

also, if a given area of section be required

$$d = \sqrt{\frac{a}{0{\cdot}7854 \cdot n}}$$

$$n = \frac{a}{0{\cdot}7854\ d^2}$$

Small tubes have also other advantages over large ones, for they may be made of thinner metal, because the strain diminishes as the radius, and the tubes being thinner will be lighter, and will interfere less with the passage of the heat from the hot air to the water to be evaporated. The following rule will give the thickness of the tubes : Let s be the tensile resistance of an inch square bar of the material in pounds, c the compressive resistance of the same, r the radius, p the pressure in pounds per square inch, t the thickness, in inches, of the metal; then, if the pressure acts outside the tubes, and the tubes are short and rigid, their thickness should be

$$t = \frac{p\ r}{c}$$

If the pressure be applied on the inside, the thickness will be

$$t = \frac{p\ r}{s}$$

The first formula must not be applied to tubes which are not rigid, and which will therefore yield by the buckling or crumpling of the material of which they are made.

Square boilers, such as those generally used for marine purposes, are strengthened by stays, which tie the flat sides and prevent their bulging when subjected to internal pressure.

Boilers should always be fitted with safety-valves and steam-gauges, the construction of which will presently be described.

CHAPTER XI.

PRELIMINARY CONSIDERATIONS ON THE APPLICABILITY OF VARIOUS KINDS OF STEAM-ENGINES TO VARIOUS PURPOSES.

The first step to be taken when it is proposed to construct a steam-engine, consists in determining the general form of the main features of the engine, without regard to the minor details; wherefore, it is proper to enter upon this subject before following up complete descriptions of steam machinery.

This chapter will be devoted to a comparison of the different arrangements already mentioned, regard being had only to the main features; such as cylinder, connecting-rod, beam, crank, &c., as applied to a variety of purposes.

Steam-engines will be first divided into condensing and non-condensing, the former being the most costly in construction, and taking up a great deal of room, but making full amends for this in the economy with which they work. The latter kind of engine is exceedingly compact, and capable of working at very high speeds, simple in construction, and cheap, occupying a small space, but very far inferior to the condensing engine in point of economy of fuel.

Engines may also be divided into three classes: stationary, marine, and locomotive. In the stationary class, we have sub-divisions according to form, as follows: beam engines, vertical engines, table engines, horizontal engines, inclined engines, oscillating engines, pendulous or inverted oscillating engines, grasshopper engines, rotatory engines, and disc engines.

Marine engines may be divided into the following classes: first, paddle engines and screw engines, according to the method of propulsion; secondly, according to the form, into side-lever engines, upright engines, inclined engines, oscillating engines, horizontal engines, rotatory engines, disc engines, &c.

Locomotive engines include those for railway purposes and those which run on common roads; they may be divided into two classes: one with the engines above the boiler and the other with the engine beneath it. They are invariably high-pressure, as it is necessary that they should occupy but small space, and be as light as possible.

Let it be required to design an engine for manufacturing purposes, then it will be necessary to consider which class of engine will be most suitable to the purpose, a rotatory motion being supposed to be required. If the neighbourhood in which the engine is to be erected be plentifully supplied with water, then it will be advisable to construct an engine on the condensing principle, for the sake of economy of working. If, however, there be not room for the bulky machinery required, then a high-pressure engine must be employed. The beam engine will be found to work very steadily, and is perhaps the most convenient form that can be adopted, when a high velocity is not required; but if the speed must be considerable, then an engine of lighter parts will be preferable. It may be desirable to examine the action of reciprocating masses thus employed.

Examining the action of the engine during one stroke, we find that we have the piston, piston-rod, &c., in a state of rest at the commencement of the stroke. These bodies are then set in motion, their velocity gradually increasing, but before the next stroke can be made, the work accumulated in these parts must be absorbed, and the manner in which this absorption is effected is one of vital importance. If the steam be simply cut off, then this work accumulating in the above-mentioned masses of metal will evidently be expended upon the bearings and joints, but if the method usually known as cushioning be adopted, the greater part of the accumulated work will be economized. By cushioning the piston is meant the introduction of the steam for the following stroke, before the termination of the previous one; then the greater portion of the work accumulated will be expended in compressing the steam, and so soon as the crank has passed the centre, or dead point, the piston will change the direction of its movement, and the compressed steam will expand, and give up the work which it had absorbed; hence the reciprocating engine may by careful management be caused to

work with great smoothness and regularity. In the more compact class of steam-engines, such as table engines, horizontal, inclined and vertical engines, a less degree of cushioning is required than in beam engines; because in the former case the moving masses do not possess so much inertia as do those of the latter class of engines. It has been proposed to use masses of metal to counterbalance the effects of the reciprocating parts of steam-engines, being of equal weight with the latter, and always moving in an opposite direction; this, however, is perfectly superfluous for fixed engines.

With regard to rotatory engines, it may be desirable to offer a few remarks in this place. In these machines there are no reciprocating parts having sufficient inertia to render them worthy of serious consideration, wherefore, high velocities may safely be used. There is also the advantage on their side, in point of uniformity of movement, as the moment of power about the main shaft remains constant for any position of the same, the variations entailed by the crank being thus avoided.

It is a great mistake to imagine that any saving is effected by having an exceedingly heavy fly-wheel, to render less evident the jerks and reactions produced by the reciprocation of the machinery of the ordinary engine; for although the velocity may be thereby rendered more uniform, yet the jerks and vibrations will still exist, although they be less evident. Hitherto rotatory engines have not been attended by results sufficiently satisfactory to induce their employment by the generality of mechanical engineers; this being due, in a great many engines, to the impossibility of keeping the valves and packings in a steam-tight condition, which defect destroys the economy of the machine, a large quantity of steam being lost by leakage, the difference between the surfaces of contact of the moving parts of the two classes of steam engine being as follows: in the reciprocating engine surfaces of contact of any desired extent may be obtained, and these surfaces may be scraped, so as to work upon each other almost perfectly steam-tight; whereas with rotatory engines, it is but seldom that good steam joints can be obtained, the engineer being, in the greater number of cases, obliged to substitute these broad surfaces of contact by others so narrow, that, practically speaking, they may be regarded as simple lines.

From these remarks it may be concluded that for the purposes above mentioned, where great steadiness is required, beam-engines may be used with advantage. Next to these, with regard to uniformity of movement, oscillating engines may be ranked, more especially when constructed with the cylinders above the main shaft, which form is known as the pendulous engine; and if this be made with a proper regard to the principles which regulate the motion of vibrating masses, it will be found to work with great smoothness.

With regard to marine engines, the following remarks will embody most of the considerations by which the engineer is directed to a conclusion as to the class of machine to be employed for any particular vessel.

The first consideration is the available space, which is generally rather in defect as regards height, of that which is most convenient; hence from time to time various means of overcoming this inconvenience have been devised. The first consisted in the employment of beams, placed beneath the cylinders, with connecting-rods attaching their extremities to the piston-rod and to the crank; oscillating engines have, however, been found, on the whole, most convenient for paddle-wheel engines.

The introduction of the screw-propeller has given rise to a great variety of designs, the main objects being to shorten the screw shaft as much as possible, and to let the engines act upon it direct; that is to say, without the use of tooth wheels, or spur gearing, as it is generally called.

With regard to locomotives, there is but little to be said, the circumstances of the case requiring always a compact design, and admitting only, in the present state of science, of the use of horizontal or inclined engines, with fixed cylinders. These cylinders are sometimes placed within the framing of the engine, and below the boiler, and at other times on the outside of the framing.

In concluding these general remarks, it is thought desirable to direct the reader's attention to the accompanying Plate, No. XI., illustrative of the main features of various descriptions of engines; the lettering is the same on all the figures:—*a* is the cylinder, *c* the piston-rod, *d* the beam, *e* the connecting-rod, *f* the crank, *g* the main shaft, and *h* the eccentric, by which the valves which admit the steam to the main cylinder are worked.

CHAPTER XII.

ON THE DETAILS OF STEAM-ENGINES.

Cylinders and Valves.

PRELIMINARY theoretical and general practical considerations having been discussed, the next step to be taken will consist in an account, principally of a descriptive character, of the various details or elementary parts of steam-engines as they exist, without regard to the purposes to which they are applied; and in following out this course care will be taken to describe fully every peculiarity of form, and to indicate the end intended to be gained by such peculiarity, without, however, entering into any considerations of a purely theoretical character.

One of the most general details of all classes of steam-engines is the steam-cylinder, which will therefore first require attention. Cylinders may be divided into two classes, fixed and oscillating.

FIG. 44.

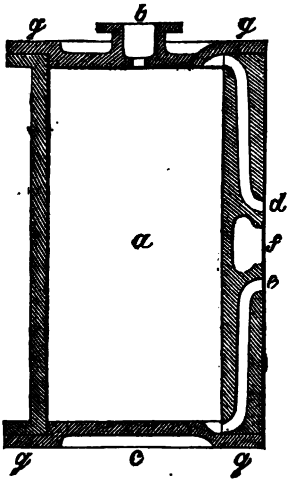
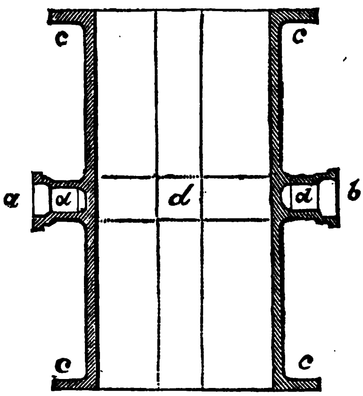


Fig. 44 represents a section of an ordinary fixed cylinder; that is to say, it exhibits the form of a cylinder which has been cut through the centre, the cut parts being exposed to view in plan or vertical section. It is of course circular; *a* represents the body of the cylinder, *b* and *c* are covers, of which however the description will be postponed for the present, the body or central part of the cylinder being first considered. It is necessary to pro-

vide means for the entrance and exit of steam to and from the upper and lower parts of the cylinder; the extremities of the passages through which the steam passes from the steam chest to the interior of the cylinder are shown at *d* and *e*, *f* indicating the entrance to the pipe through which the steam, having done its work, makes its escape. These entrances are called ports, and will subsequently be fully described. The body of the cylinder is furnished at top and bottom with rims called flanges, which serve for the attachment of the covers by means of bolts and nuts, at *g g g g*.

Fig. 45 represents a section of an oscillating cylinder, taken at right angles to the ports. The feature which distinguishes this class of cylinder from the foregoing, consists in the manner of

FIG. 45.



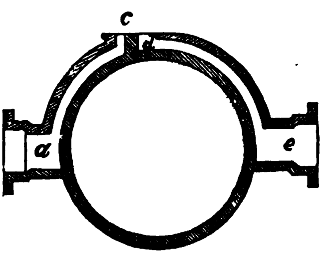
supporting it, so that it may oscillate with ease. *c c c c* are the flanges, the covers are not shown. *a* and *b* are, as it were, short shafts, cast on the sides of the cylinder, and diametrically opposite to each other; they are accurately turned, and are supported in bearings which fit them truly. These short shafts are termed trunnions, the parts which rest on the bearings being in this, as in other cases, called journals.

It is evident that the motion of the cylinder precludes the use of the method of attaching the steam-pipe commonly employed in fixed engines, hence some peculiar form of construction must be had recourse to; wherefore, the steam is conducted through the trunnions, to and from the valve chest. The means of

making a steam-tight joint, between the fixed steam-pipe and the moving trunnions, will be explained in a subsequent page. The steam is conducted from one trunnion to the steam-chest by a hollow band passing round the cylinder, and in a similar manner from the steam chest to the other trunnion, after having done its work in propelling the piston; its passage may however be better described by the assistance of the horizontal section Fig. 46, which is taken through *a b*, the steam band in the former being represented by the dotted lines *d*.

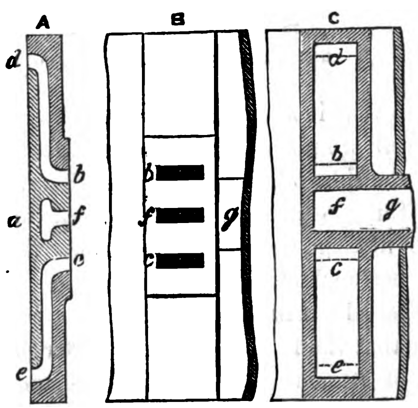
In the horizontal section, Fig. 46, the shaded parts represent the metal, *a* and *e* being the trunnions. The steam by which the engine is to be impelled enters at *a*, and passes thence into the steam chest at *c*, after which it is admitted by the slide valve to the cylinder, and having done its work, passes into the exhaust port *d*, and finally out at the trunnion *e*, into the condenser or atmosphere, as the case may be.

Fig. 46.



The steam ports attached to the cylinder, and forming part of

Fig. 47.



the same, next require description. In Fig. 47, *A* is a section taken through the cylinder, that part, however, which shows the

ports only, being given; *B* is a front elevation of the ports, and *C* is a section produced by a plane cutting the steam passages by passing through the centres of the vertical parts of the same, parallel to the port faces. The lettering is the same in each case; *a* is the interior of the cylinder, *b* and *c* the steam ports or external openings of the steam passages, which are made narrow in order that they may be suddenly opened and closed by a slight movement in the direction *b c* of a plate resting upon the port faces; *f* is the port into which the exhaust steam passes, whence it escapes through the exhaust pipe *g*. The means by which the entry and exit of the steam are regulated will be described in a subsequent page, hence no further comment upon the port faces is requisite, except the observation that the steam passages may be shorter, the ports wider apart, and the port faces sometimes made in two separate parts: one for the top face and the other for the bottom.

Having now fully described the form of the steam cylinder, it is necessary to render some account of the means employed in its manufacture.

The first step towards the construction of the cylinder will consist in determining its dimensions, and in order to obtain results of a satisfactory character, we must necessarily employ proportions which may be demonstrated to be the most economical. With regard to the diameter of the cylinder requisite for a given horse-power, that will be found in the following formula.

Let h = the horse-power required.

n = the number of revolutions of the main shaft per minute.

l = the length of stroke.

p = the total effective pressure per square inch and pounds upon the piston.

d = the diameter of cylinder in inches.

Then:

$$d = 145\sqrt{\frac{h}{l\,n\,p}}$$

which formula is derived from the considerations given in a previous chapter. We may here observe that p, the total effect of pressure, is taken to represent the mean pressure of the steam for

high-pressure engines, and the mean pressure of steam plus the mean pressure of vacuum in condensing engines. For the latter class, there is a rule for nominal horse-power, the pressure being taken at seven pounds per square inch, and the speed of the piston at two hundred feet per minute. Working out the calculation upon these data, the following formula will be found to approach absolute truth very nearly

$$d = 5{\cdot}5 \sqrt{h}$$

These rules will suffice for the diameter of the cylinder, but it yet remains for the engineer to determine the thickness of metal. The absolute thickness requisite to withstand the bursting force is much less than can be applied in practice, hence the formulæ assumed to meet this requirement only are of little practical value; we therefore insert one of a somewhat different character, which satisfies the conditions required by the increasing weight of the cylinder. We insert the formula without giving the steps by which it was obtained, for the two following reasons; firstly, space would thereby be occupied in a manner which is undesirable in a work intended for practical reference; and secondly, they are of so simple a character that little difficulty can be found in their comprehension.

Let t = the thickness of the metal in eighths of an inch, then;

$$t = \frac{p\,d}{440} + \sqrt{d}$$

$$= \sqrt{d} \left\{ \frac{p\sqrt{d}}{440} + 1 \right\}$$

It is almost needless to observe that in this formula the value of p must be taken at a maximum. It may be desirable here to insert an example illustrative of the use of these formulæ.

Let a cylinder be required for a condensing engine whose nominal power is sixty horses, then the square root of sixty is:

7·75 nearly;

hence,

$$d = 5{\cdot}5\sqrt{h} = 5{\cdot}5 \times 7{\cdot}75 = 42{\cdot}6 \text{ inches}$$

$$= \text{say } 43 \text{ inches.}$$

For the thickness of metal, supposing $p = 30$ lbs., will be found,

$$t = \frac{p\,d}{440} + \sqrt{d}$$

$$= \sqrt{d}\left\{\frac{p\sqrt{d}}{440} + 1\right\}$$

$$= 6{\cdot}55\left\{\frac{30 \times 6{\cdot}55}{440} + 1\right\} = 6{\cdot}55 \times 1{\cdot}446 = 0{\cdot}947 \text{ eighths.}$$

The thickness will therefore in practice be made one inch.

It frequently happens that the cylinder is strengthened by bands passing round it, but cast in the piece with the cylinder itself.

The next step will consist in drawing sections, plans, and elevations of the cylinder to scale, care being taken to delineate accurately the ports and steam passages, which latter it will be found desirable not to bring quite through the metal; but on the contrary, it will be preferable to leave the ends closed by a slight film of metal, for reasons which will subsequently be mentioned. The drawings being made, the pattern-maker may prepare a template and core-boxes; the former will correspond to the general exterior profile of the cylinder, and the latter will contain cavities similar to those which form the steam passages, in order that cores of a proper form to exclude the liquid metal from those passages during the process of casting may be prepared. The mould will then be made in *loam*, and the cylinder cast according to a method similar to that described for the production of a melting-pot in the chapter on Moulding and Casting.

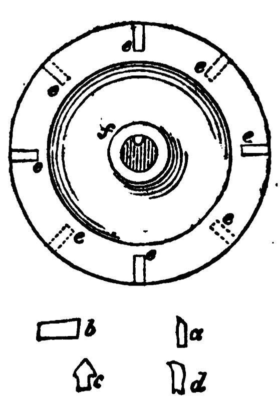
Small cylinders may, however, be cast by the ordinary means, in which case a pattern will be required, such pattern representing the general external form of the cylinder, but with this exception, that wherever an aperture is to be formed in the cylinder there will be a protruding piece, called a *print*, on the pattern, in order to form recesses wherein the extremities of the cores requisite to produce such apertures may be inserted, in order to afford them requisite means of support. These cores may also be further supported and retained in position by means of broad-headed nails, driven into the sand. The casting is subsequently conducted in the usual manner. When the casting

is cool, it is carefully examined, and if defective, it is put aside to be remelted, being known as a waster; but if perfect, it is first treated with a piece of hard oven coke, with which it is well scoured, in order to remove the greater portion of the hard silicious coating with which it has become covered, on account of the heat of the molten iron vitrifying a portion of the sand in its neighbourhood. After scouring, the cylinder may be further cleansed by means of an old coarse file, after which it will be ready to be handed over to the turners and fitters, whose operations upon it next require attention.

The first operation to which the cylinder will be subjected by the turner, will consist in boring the cylinder cutting off the head or runner, and facing the flanges; and it is in this operation of boring that the advantage of casting the cylinders with the steam passages closed is observed; for if the cylinder were cast with it open, the cutting tool would be damaged by the concussions produced every time it passes over the opening; and after the boring the thin film of metal left may readily be cut away with the chisel, and the edges of the ports filed smooth. We have already described the boring-bar and head in the chapter on Workshop Machinery, but nevertheless deem it desirable here to insert an illustration of the boring-head, and cutting tools commonly used with it.

In Fig. 48, the upper sketch represents a boring-head made of cast-iron, and accurately bored in the centre, and turned upon the periphery. The boring-bar upon which it travels from end to end is shown by the shaded part at *f*; *e e*, &c. are slots in which the boring tools are fixed by wedges, the boring-head being slightly less in diameter than the interior of the cylinder to be bored. The head is first used with the tool shown at *a* and *b*, which acts almost as a scraper, but which is sufficiently accurate in its action to take the rough cuts satisfactorily. The finishing cut is taken

Fig. 48.



with the point tool shown at *c* and *d*; and in taking this cut it should be borne in mind that, as by the friction of boring the cylinder becomes heated, and therefore expanded, the operation should not be stopped a sufficient time to allow it to cool and contract, whereby a sudden variation in the bore would be produced.

It will be observed that there are great difficulties in boring cylinders, when compared with the process of turning, as the cutting tools in the former operation can scarcely be brought into operation at a less angle than 90°; hence they must of necessity act rather as scrapers than as cutting tools, properly so called.

In the mots accurately turned cylinders we see that the interior form is not that of a perfect cylinder, but of a frustrum of a cone of very small angle, that is to say, with very little taper, this form being thus produced. On starting the work the cylinder is cold, but as the boring proceeds it becomes heated, which effect will not be noticed in the boring-head, but only in the cutting tool. The result is that the cylinder expands while the radius of the cutting edge remains almost constant; hence that end of the cylinder at which the boring was commenced will ultimately possess a diameter somewhat greater than the other parts, but the difference is far too trifling to be taken into account in practice; nevertheless it is desirable to be acquainted with the true state of affairs.

The cylinder, finished with the point boring tool, presents on its interior surface the appearance of a screw furnished with an extremely delicate thread; hence it may readily be believed that with a new cylinder there is at first much friction, but in a few days the roughness wears off, and the interior of the cylinder becomes perfectly smooth and bright.

A just consideration of these facts leads to the conclusion that it is unfair to test the powers of an engine immediately after it is erected; and that results more nearly approaching the truth may be readily obtained after the machinery has been at work for a few days.

The method of boring the cylinder having been discussed, it will be necessary to pass on to the other operations connected with the formation of this important element, which contains, as

it were, the vital force to which the mechanical movements of the steam-engine are due, and upon which they are dependent.

The next operation will consist in facing the flanges, which may be done by attaching a temporary slide apparatus to hold the cutting tool, in order to allow a motion of the same from the interior of the cylinder towards the exterior the cut being commenced at the internal edge of the flange. The method of completing the cut is obvious, hence no further description of it is necessary.

The next step will consist in the preparation of the port faces upon which the valve which regulates the admission of steam to the cylinder moves. These port faces are first planed and filed, and then reduced to a surface as nearly plane as can be obtained by the following means.

A surface-plate of the form already described in a previous chapter is smeared with ruddle or other similar colouring matter, and then placed upon the port faces and gently moved about in contact with them; then it is evident that those points on the port faces which are most elevated will alone be in contact with the surface-plate, and therefore will become marked with the colouring matter; the highest points in the surface will become thus indicated by the colouring matter taken up by them, and may be reduced by scraping. The operation with the surface-plate is again and again repeated, until it is found to bear uniformly upon the port faces. The method of adjusting the slide to the port faces will subsequently be described.

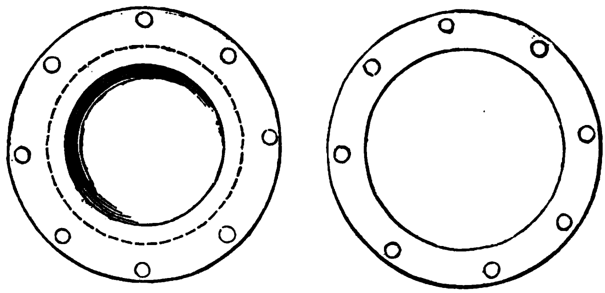
The foregoing operations having been satisfactorily conducted, it remains to drill in the flanges of the cylinder the holes through which the bolts by which the covers are attached to the cylinders pass; and also the bolt holes in the port face flanges by means of which the slide jacket will subsequently be attached.

If the cylinder be intended to oscillate, it will be furnished with trunnions, which must of course be accurately turned.

The cylinder covers will not require attention; they may be classed under two heads—plain covers, and covers furnished with an air-tight stuffing-box, to allow a rod to work through it, air and steam-tight One of each class is usually required; a section of the plan is shown at the bottom of the cylinder, Fig. 49. This

is the form generally used for small engines; in larger ones, it will be frequently convenient to make the covers concave on the inside, thereby affording extra strength; it is of course circular in plan. The upper cover will be similar in every respect, except

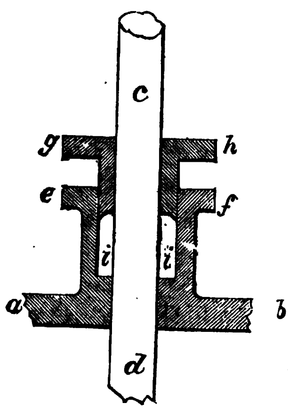
FIG. 49.



that an air and steam-tight aperture must be provided for the passage of the piston-rod. The cylinder covers must be turned on their peripheries, and holes must be drilled in them corresponding with those in the flanges of the cylinder.

The reader's attention will now be directed to the means usually employed when it is requisite that a rod should work through an aperture, air and steam-tight. This is effected by means of a contrivance called a stuffing-box, furnished with a gland.

FIG. 50.



In Fig. 50 is shown a section of a stuffing-box and gland; *c d* is the rod, which is required to work air and steam-tight through an aperture in the plate *a b*; upon this plate, and in one piece with the same, is cast a cylindrical box, or cylinder, furnished at the top with a flange, *e f*; this box, technically termed the stuffing-box, is bored at the bottom accurately to fit the rod *c d*, and at the upper portion it is bored out somewhat larger, as shown, to have a cylindrical cavity round the piston-rod. To this box is fitted a gland, which gland is, in fact, a cylinder fur-

nished with a flange, *g h*. This cylinder, or gland, is bored throughout its length so as to fit accurately the rod *c d*, and its exterior surface is turned down to such a diameter that it may slide with ease into the stuffing-box already described. A closed space, *i i*, will then exist around the rod *c d*; this space is filled with greased hemp, as packing, or with some other suitable material. The bottom of the gland is not faced up flat, but concave, as shown; the bottom of the stuffing-box being similarly formed, in order to force the packing against the rod *c d*; but with some kinds of packing this construction is dispensed with, flat faces being used. The packing is compressed by tightening up the bolts *e g*, &c., whereby the gland is forced into the stuffing-box. The gland, if small, may be fixed in a dog-chuck, and bored out by a side tool, but if very great accuracy is required a small boring-bar may be used. For boring articles similar to glands, the following contrivance is very convenient. A small boring-bar is fixed in an ordinary drilling-machine, the boring-bar being furnished with slots, in which cutting tools may be firmly fixed. This bar passes through a circular aperture in the centre of the drilling table, being thereby steadied. The work to be bored is accurately fixed upon the centre of the drilling table, the boring-bar passing through its axis.

A proper boring tool being fitted to the boring-bar, the boring of the work is proceeded with, the cutter being caused to descend as the boring proceeds by means of the usual feed-motion of the drilling machine.

In many cases the stuffing-box is lined with brass, and the gland either lined with brass, or made entirely of that metal.

The foregoing description of a steam-tight aperture will answer generally for every case where a rod is required to work as above, no matter whether it be a piston-rod, slide-rod, or other similar element.

The next details to be considered are those referring to the admission of steam to cylinders of the oscillating class. We have already mentioned that the steam is admitted through one trunnion and exhausted through the one opposite, and it now remains to describe the connexion between the trunnion and the steam-pipe.

Two methods of constructing this joint will be described. In

the accompanying Figs. 51 and 52, *d e* is a portion of the cylinder, *c* the steam-band surrounding it, *b* the interior of the trunnion, *h h* the portions embraced by the trunnion bearings whereby the cylinder is supported, *a a* the extremity of the steam-pipe. This steam-pipe is at rest, while the trunnion oscillates so that it has

FIG. 51.

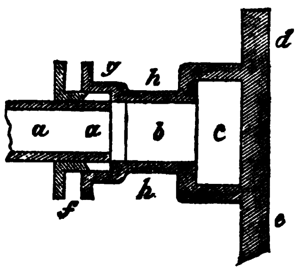
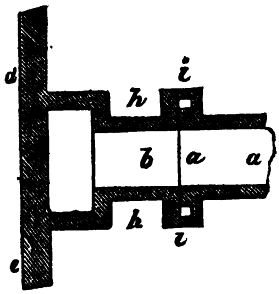


FIG. 52.



a circumferential motion about the steam-pipe. In Fig. 51, the joint is made steam-tight by enclosing the extremity of the steam-pipe within the stuffing-box, as shown; it being necessary, in forming the parts, to bore the trunnion and gland, and to turn the extremity of the steam-pipe so that it shall fit accurately the interior of the trunnion. The arrangement of the Fig. 52 is, however, much simpler, and, we think, preferable. In this case no gland is used, but the ends of the trunnion and steam-pipe are faced, and rest in contact with each other, the joint being kept steam-tight by a ring, *i i*, let into a recess in the extremity of the steam-pipe. By this method the boring of the trunnion and the turning of the steam-pipe are avoided.

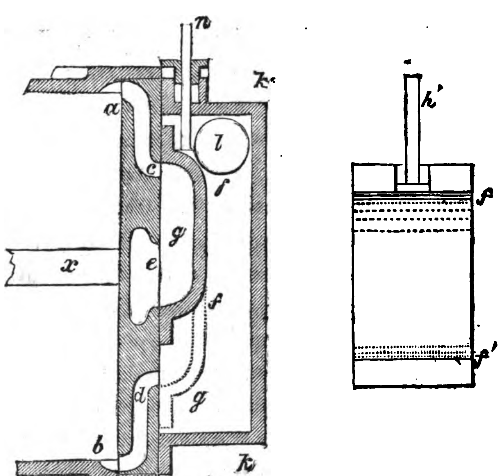
The reader's attention will now be called to the means of admitting steam to each extremity of the cylinder, and allowing of its escape at the termination of the stroke. It will be necessary in the first place to consider what requires to be done; and in the next place the various means of doing it, avoiding, however, encumbering the space at disposal with accounts of methods displaced by modern improvement.

There exist in the neighbourhood of the cylinder two pairs of passages; the first pair have each one extremity communicating

with the valve arrangement, their other extremities communicating with the interior of the steam cylinder, one communicating with the top, the other with the bottom of the same. We have also the second pair of passages; one connects the boiler with the valve arrangement, whilst the other connects the valve arrangement with the exhaust; and what is required to be done is this: to let the top passage to the cylinder communicate with the boiler when the bottom passage is open to the exhaust, and *vice versâ;* and this has to be done in a peculiar manner, in order to cause the engine to run in the direction desired, and to prevent the possibility of its reversing itself.

It is desirable to commence the description with the simplest form of valve, and then to proceed by steps to the more complicated. Fig. 53 represents a section of the steam ports and short slide valve, surrounded by the steam chest, and also a view of the

Fig. 53.



back of the valve; *a b* is part of the interior of the cylinder, the steam passages opening into the cylinder at *a* and *b*; *x* is a portion of the piston; *c* and *d* are the external steam ports, *e* being a port leading to the exhaust (for front view of port faces, see Fig. 47); upon the port faces slides a box, *f f*, called a short slide valve; the box is of such width as to cover the ports, and

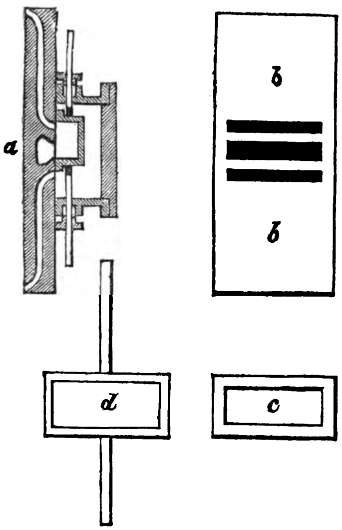
of such length as to cover one steam port and exhaust port; *k k* is the steam chest, which is bolted on to the port faces, and within which the slide valve moves. The surfaces of contact between the slide valve and the port faces are planed and very accurately finished by means of a planometer, and making the two surfaces act as planometers to each other, so that no steam shall escape through the valve. The steam chest *k k*, is kept full of steam by means of a pipe coming from the boiler, the extremity of which is shown at *l*. The slide valve is moved by means of a rod (*h*) passing through a gland in the steam chest; *h′ f′ f″* show a back view of the valve. With the valve in the position shown, it is evident that the steam entering the steam chest will pass through the port *d* into the bottom of the cylinder at *b*, and the steam in the upper part of the cylinder will pass out through the passage *a c*, into the cavity of the slide valve, and thence into the exhaust port *e*. When the valve is moved into the position shown by the dotted lines *g g*, the direction of the steam will be reversed, the steam in the chest entering the upper part of the cylinder, whilst the steam in the lower part of the same passes out through the valve into the exhaust. The valve is kept close up to the port faces by the pressure of the steam acting at the back of it, which is much in excess always of the pressure on the interior of the valve, because that cavity constantly communicates with the exhaust port. This valve is exceedingly compact, and very generally used. In order to ensure the motion of the engine always in the desired direction, it is necessary that the steam port should be partly opened before the commencement of each stroke, or, in other words, that it should be in advance of the piston; this is called giving the valve a lead. In order to cut off the steam at an earlier period of the stroke than would ordinarily be accomplished by the valve, its edges are made somewhat wider than the steam ports; this is known as giving the valve lap.

Slide valves of the foregoing form are in some engines, such as locomotives, made exceedingly short, in order to reduce as much as possible the motion, or travel as it is called, of the valves. The slide valve is then frequently moved by a frame which surrounds the box part of the valve, having attached to it rods which pass out at the ends of the steam chest. By this

arrangement the valve can readily adjust itself to the pressure which keeps it up to the port faces without straining the valve rods.

In Fig. 54 views of the very short slide valve are shown: *a* is a section of the valves, steam passages, and chest; *b*, a front elevation of the ports, which are long and narrow; *c*, a front view of the slide; and *d*, the slide rod and frame. It is evident that with these narrow ports a very slight movement of the valve is sufficient to open and close them.

Fig. 54.



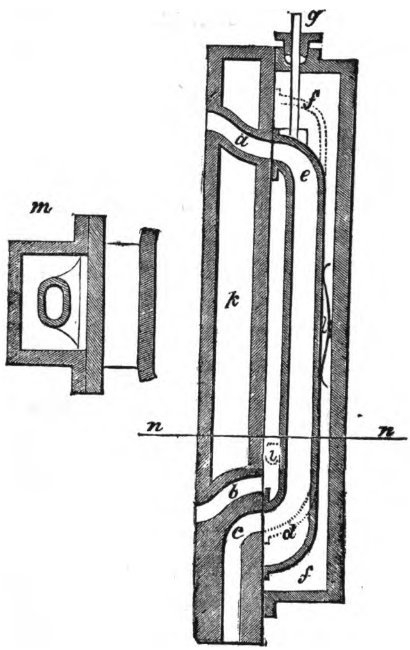
The next valve described will be a long valve, which is, however, in some respects, somewhat similar to the foregoing short slide.

It may here be mentioned, before proceeding further, that the number of pieces in which the steam jackets are made may be determined from the figures by observing the occurrence of flanges whereby the various parts are bolted together.

Fig. 55 represents a section of the slide mentioned above. It is a long tube; *a* and *b* are the steam passages, *c* is the exhaust port, *k* is a hollow in the metal to lighten the cylinder casting, *d e* is the slide, *f f* the steam chest, and *g* the slide rod. With the slide in the position shown, it is evident that the steam in the chest will pass round the slide into the bottom of the cylinder at *b*, and the steam in the upper part of the cylinder will pass through the whole length of the slide rod into the exhaust *c*. When the valve is raised to the position shown by the dotted lines, the steam from the chest will pass through *a* into the upper part of the cylinder, while the steam in the lower part passes into the valve and thence to the exhaust, the aperture at the lower part of the valve *d* being sufficiently wide to cover the ports *b* and *c*. The apertures at the extremities of the slide

valve are of course rectangular, which form is gradually changed to circular or elliptical in the centre part of the tube. The port faces are in every case surfaced as above described. With this long valve it is found necessary to have a light spring *l*, to press

Fig. 55.



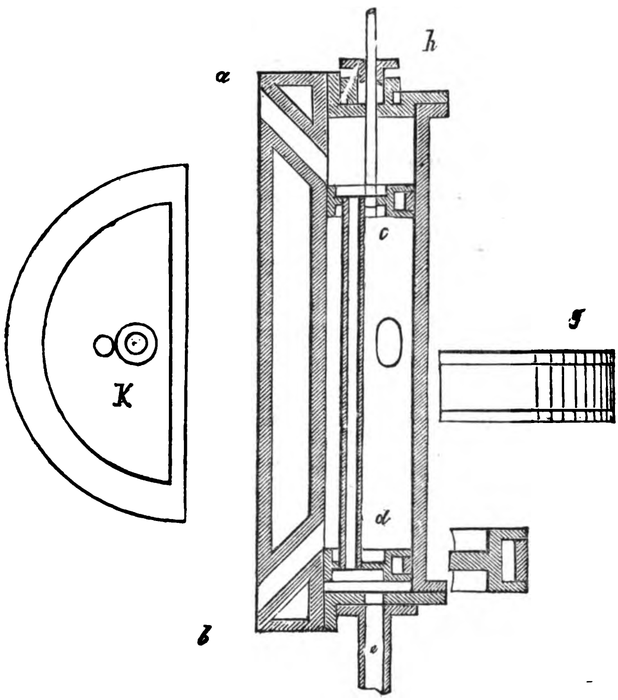
it against the port faces, otherwise, when the steam is shut off, it will fall away. The slide jacket is made of a semicircular or D shape, or oblong, as shown at the horizontal section *m*, which section is formed by a plane cutting the slide on the line *n n*.

The next valve to be considered is the D valve, of which views are shown, Fig. 56; this, like the former, is a long valve.

In Fig. 56, *a* and *b* are the steam passages to the cylinder, *c* and *d* are two D-shaped slides, as shown in place at *f*, these slides being connected by a hollow pipe; *c d e* is the exhaust pipe, which, contrary to those already described, is independent of the cylinder, proceeding from the steam chest. The D-shape valves are accurately fitted to the steam jacket, which is truly shaped up, being rendered steam-tight at the back or convex

part by metal slips pressed against the steam jacket by springs; these slips being shown at the elevation *g*, and at the enlarged section *k*. The slides are moved by a rod *h*, attached to a lug on the front part of the upper valve. The steam is admitted between the D-shape slides, and in the position shown it is evidently

FIG. 56.



passing through the passage *b*; the steam in the upper part of the cylinder is passing into the steam jacket, thence through the tube *c d* to the exhaust pipe *e*. If the slides be now caused to rise above the ports, as shown by the dotted lines, then it is evident that the steam will flow into the cylinder at *a*, and out of the bottom of the cylinder at *b* into the exhaust.

It is not absolutely necessary in this form of valve to make the steam jacket continuous, but it may be made in two parts, as shown, Fig. 57; the tube connecting the slides being carried through stuffing-boxes, in each of the short steam jackets.

The steam is admitted to the inner end of each steam jacket, that is to say, to the parts nearest *c d* in Fig. 56. In the position shown, the steam is passing into the bottom of the cylinder, and out of the upper part of the cylinder, through the connecting tube into the lower jacket, and thence into the exhaust pipe.

Fig. 58 represents a very ingenious form of long valve. The valves consist of two round slides or pistons, fitted with packing

FIG. 57.

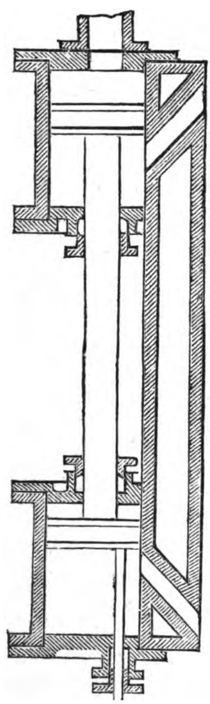
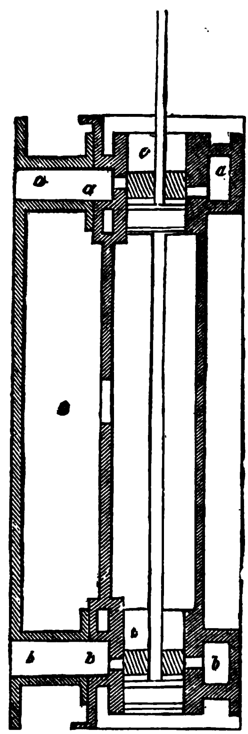


FIG. 58.



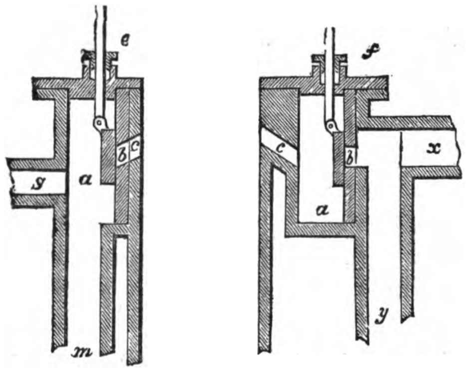
rings, pressed outwards with springs. The steam is admitted at *s* between the slides, and around the valve jacket at each end is a casing communicating with the exhaust, and also, nearer the centre of the jacket, there are circular passages, *a a*, *b b*, communicating with the steam ports *a* and *b*. Diagonal slits *c c*, open a communication between the steam ports and the

interior of the steam jacket. In the position shown in the figure it is evident that the steam admitted at *o* is passing through the lower set of diagonal slits into the steam passage *b*, whilst the steam in the upper part of the cylinder is passing from the passage *a a* through the upper series of slits, and out at the end of the steam jacket. If the valves be moved up past the diagonal slits, the direction of the steam will be reversed.

In some instances two sets of valves are used, one for the steam and one for the exhaust, and in this arrangement the ports at top and bottom are worked by distinct slides, four slides being altogether required. These slides consist of flat plates accurately surfaced to fit the port faces, and by having the exhaust and steam slides separate, they may be manipulated independently of each other, which affords great facilities for regulating to a nicety the admission and exhaustion of the steam. As the steam and exhaust ports require a somewhat different arrangement, in order that the pressure of the steam may keep the slides against the faces on which they work, we give two sketches of the arrangement of these slides.

In Fig. 59 the section *e* represents one of the steam slides,

FIG. 59.

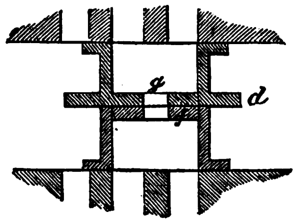


and *f* one of the exhaust slides. In the former, *s* is the steam-pipe, *a* the slide, *c* the upper steam passage, and *b* the port face; at *m* the steam-pipe is continued to supply the lower valve; as shown, the valve is closed. At *f* the exhaust slide, *c* is the upper

exhaust passage, *a* the slide valve, *b* the port face, *x* the exhaust pipe, and *y* a pipe communicating with the lower valve.

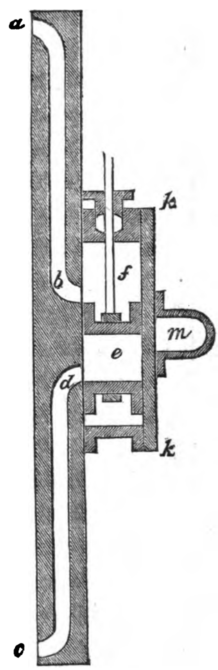
From these illustrations we see that the valves are so arranged that the greatest pressure upon them is on the side opposite the port face.

Fig. 60.



We will now call attention to some locomotive slides. The slide valves for the two cylinders shown Fig. 60, are placed on vertical faces in a single steam chest between the pair of cylinders. One slide has a plate, *d*, cast or bolted on its back, and planed to accurate parallelism with the working face. The other slide has an open box cast upon its back to receive a piston, *f*, having an upper or end face, also planed parallel to the end face. The piston is fitted steam-tight in its cylinder or box, and its planed top bears steam-tight against the face of the plate *d*, in working By this arrangement the slides are relieved from one-half the steam pressure: and to assist the free exhaust, a port, *g*, is formed in the back plate, *d*, of one of the slides, to allow the steam an additional exit through the exhaust port of the opposite valve. The other parts of this valve are as usual. Various kinds of valves called equilibrium valves, have from time to time been produced, and one example of the class is shown in Fig. 61. *a b*, and *c d*, are the steam passages, *e* the valve, *k k* the steam chest, *m* the exhaust pipe. The slide valve works accurately between the port face and the interior of the steam chest; it is kept steam-tight by packing rings on the surface *f f*, which are pressed against the interior of the

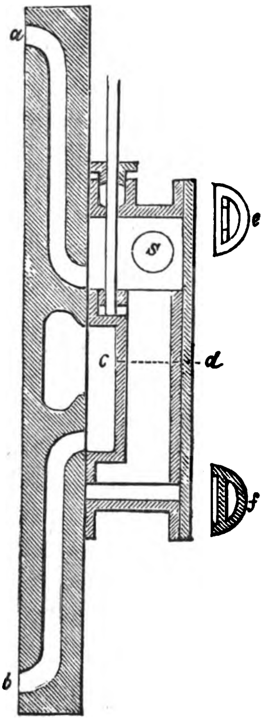
Fig. 61.



steam chest by springs at the back. All the working faces must of course be accurately surfaced. In the position in which the valve is shown, it is evident that steam is entering the upper steam passage and leaving the lower one, passing straight through the valve into the exhaust pipe *m*. On raising the valve the direction of the steam will be reversed. This valve is evidently in equilibrio, as the steam pressure affecting it equally in both directions, will not exert any action upon it.

There is another kind of equilibrium valve which, although derived from the common short slide valve, is in principle almost identical with the long D valve. A section of it is shown, Fig. 62. *a* and *b* are the steam-passages, *c* the valve, having a cavity corresponding to that of the short slide, but having at its back a semi-cylindrical tube, packed to fit the steam-chest perfectly tight. In this valve the steam, when being admitted to the upper port, passes direct from the steam-pipe *s* to that port, while the steam from the lower end of the cylinder passes out through the cavity *c* of the valve. When the valve rises, the steam traverses its length and passes into the bottom port; the steam in the upper part of the cylinder then exhausting through the cavity *c*. *e* is a plan of the valve, and *f* a section of the same. On the line *c d*.

Fig. 62.

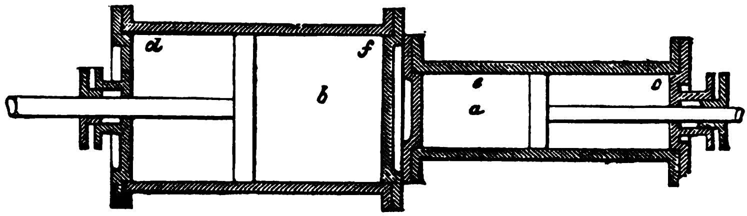


Before taking leave of the subject of slide-valves it will be necessary to pay some attention to those used for double-cylinder engines. And in the first place, the direction of the steam must be carefully observed. It may be best explained by means of a diagram.

In Fig. 63 two cylinders are shown, fitted with pistons, and of these cylinders *a* is much smaller than *b*. It is evident that if high-pressure steam be used in *a*, and after one stroke of the

piston has been made, a communication be opened with one extremity of the large cylinder, the steam will pass out of the small cylinder into the large one, because it may thereby expand, and in so doing it will impel the piston in the large cylinder. The

Fig. 63.

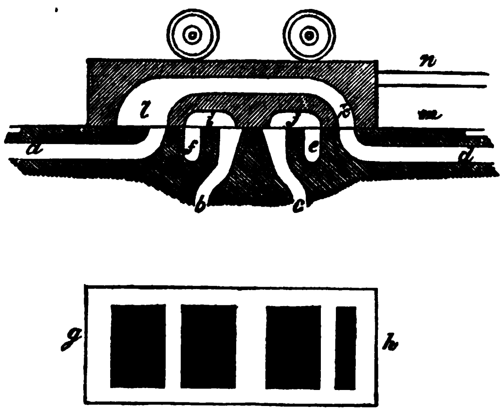


advantage gained is this: that after the steam has done all the work of which it is capable in the small cylinder, it does work in the large cylinder, equivalent to the traverse of the large piston multiplied by the mean pressure in the large cylinder, and by the difference between the areas of the two pistons.

Let it be required to construct port faces and a valve of such form that the steam may run as follows:—first, *say*, into the upper part of the small cylinder, that is to say, into the front end *c*, thence into the end *d* of the large cylinder, and finally from thence into the exhaust. Then the steam which passes into the end *e* of the small cylinder, will pass thence into the end *f* of the large one, and thence into the exhaust. The valve arrangement required is shown (Fig. 64): *a* and *b* are the ports to the large cylinder, *c* and *d* those to the small one, *e* the steam port, and *f* the exhaust port. The valve consists of a rectangular block of metal, kept upon the port faces by rollers acted upon by springs, and in this rectangular block or valve certain recesses and passages are cut or cast; *i* and *j* are recesses similar to those in small slide valves, and *k l* is a long passage similar to that in the long valve. In the position shown in the figure, the movement of the steam is as follows. From the steam port *e* the steam is passing through the recess *j*, into the lower port *c* of the small cylinder; the steam in the upper port of the small cylinder is passing from the port *d*, through the long passage *k l* into the front part of the large cylinder, and the steam in the

lower part of the same is passing from the port *b*, through the recess *i*, into the exhaust port *f*. If the slide be now moved forward the steam will then pass from the steam port *e*, through the recess *j*, into the port *d*; from the port *c*, through *i*, into the

Fig. 64.

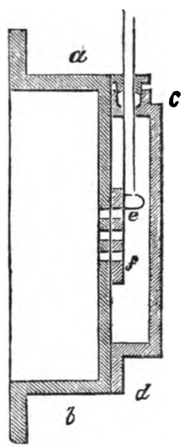


port *b*, and from the port *a* into the extremity *l* of the long passage, and out at the exhaust *f*. It cannot pass out at the end *k* of the passage, as that will be closed by contact with the part *m* of the port face. *n* is the slide-rod; *g h* is a front view of the slide-valve. There are many varieties of slides for double-cylinder engines, some of which exhibit great ingenuity, but the foregoing example may be regarded as a type of most of them, wherefore we shall now take leave of this subject.

The next part of the cylinder apparatus which strikes the observer's eye, is, when such is used, the expansion valve; the object of which is to supply a means of cutting off the steam from the cylinder at any part of the stroke of the piston, independently of the action of the slide-valve. These valves are usually of simple construction, and Fig. 65 exhibits a section of one form of expansion valve. Let *a b* be the slide valve jacket or steam chest within which the slide valve performs its usual duty. The steam is not admitted direct to this chest, but to another one, *c d*, placed at the back of it. *e f* is a flat plate of metal, accurately surfaced and fitted to the back of the slide jacket, in which three, or more or less, as the case may be, longitudinal slits are made, an equal number of slits being made in the plate *e f*, and so disposed that

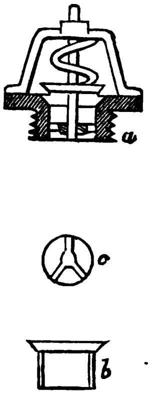
in one position they coincide with the ports in the back of the slide jacket. It is evident that while the expansion valve, as it is called (ef), is in the one position mentioned above, steam will be freely admitted to the cylinder; but a slight movement will cut it off, and the narrower the slits the more suddenly may the steam communication be closed. This motion is imparted to the valve sometimes by an eccentric, but more generally by a cam, as will hereafter be explained. When the slits are very numerous the valve is called a grid-iron valve.

FIG. 65.



While on the subject of sliding valves, we may mention that all the flat surfaces must be truly planed and scraped, after which operation they will present a mottled or patchy appearance, being a very near approach to a true plane, but consisting in reality of small irregular hollows and ridges. When the surface is planed only, it consists of numerous grooves and furrows, but approaches most nearly to an accurate plane when it is truly ground with very fine grounding powder, the operation, however, being so inconvenient that it is not practised for flat work. After the slides have been in use for some time, they present on their surfaces a bright appearance, exercising also a chromatic effect probably due to thin layers of oxide on the surface of the metal polished by friction. In fitting up the valves great care must be taken that when finally set in position they are perfectly free from any kind of grit or dirt, otherwise the faces will be injured.

FIG. 66.

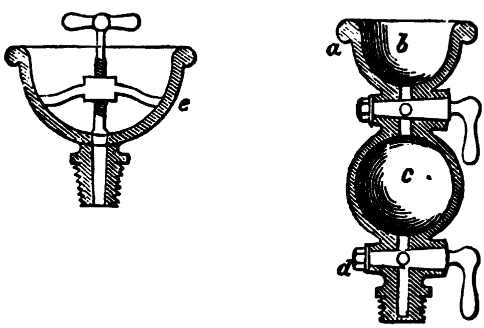


It sometimes occurs that water collects in the cylinder, and as it cannot be readily expelled through the ports, it is necessary to provide some special means of exit. For this purpose a valve of the form shown (Fig. 66) is frequently used. It consists of a plain conical valve, with a spindle working in guides, or with a stalk. It is kept in its seat by the action of a spring. The apparatus may be screwed into the cylinder cover, or otherwise be made to communicate

with it. If any water accumulate in the cylinder, the piston will, at the termination of its stroke, force it out through the valve. *a* represents a section of a valve and seat, suited to be screwed on to a cylinder cover. The valve is furnished with a spindle moving in guides. *b* and *c* exhibit an elevation and bottom plan of a stalk valve removed from its seating.

There is yet another kind of fitting which demands our attention in connexion with the cylinder; it is a grease-cock, the object being to supply lubricating material to the internal parts of the apparatus while it is at work. We show at Fig. 67 sections of two forms of grease-cock, both intended to be screwed into the cylinder or other part where they may be

Fig. 67.



required. In the section *a* the lubricating material is poured into the cup *b*, then by turning the stop-cock between *b* and *c*, the grease flows into the reservoir *c*. This cock is then closed, and the lower one opened, when the grease will flow into the vessel to be lubricated. At *e* is shown a class of grease-cock suitable for low-pressure or condensing engines. The cup is closed at the bottom with a valve, capable of being raised by a screw on turning the handle shown in the section. The method of using it is as follows: when the piston is receding from the grease-cock, and there is consequently a vacuum formed beneath the latter, the valve is opened, upon which the pressure of the atmosphere forces a portion of the lubricating material into the cylinder.

The cylinder is fitted also with a cock for blowing the steam through both ends at once.

Now that we have described the form and construction of the cylinder, and those parts which are attached to it, we will pass on to the next class of general elements.

CHAPTER XIII.

ON THE DETAILS OF STEAM-ENGINES—(*Continued*).

Pistons, Rods, Beams, Governors, &c. &c.

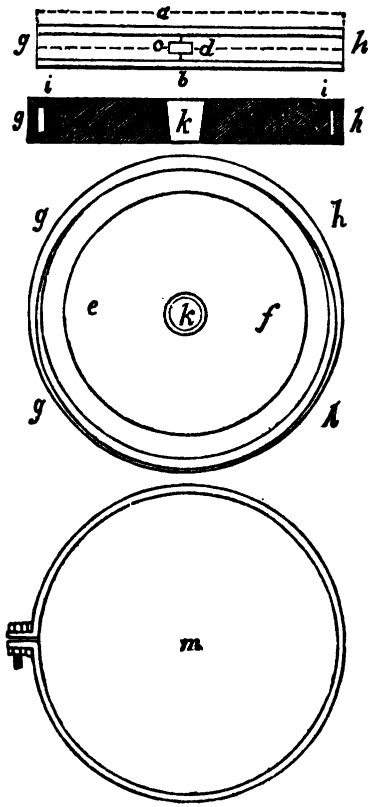
The steam cylinder having been fully discussed, with its external appendages, it is necessary to examine its interior mechanism; the first and most important part of which is the piston, upon which the steam acts directly, and to which it communicates its energy. It is evidently very necessary to exercise much care and ingenuity in order to obtain a satisfactory result; the requirements being that the piston shall fit the cylinder as nearly as possible air and steam-tight, that it shall be as durable as possible, and move with the least possible amount of friction. With the metallic packing now exclusively used, results in practice very satisfactory, fulfilling as nearly as possible the above requirements, have been arrived at, the leakage being equal to an aperture about the five-thousandth of an inch in width.

It is advisable to commence the description with the simplest form of piston, observing, however, previously, that the aperture in the centre of the piston is intended to receive the piston-rod.

Fig. 68, *a b*, and the following sketches, show views of a simple form of piston. The first view is an elevation, the second a section, and the third a plan. *a b* are the top and bottom surfaces of the piston, *g h* a cut packing ring, *c d* a tongue piece, to prevent the leakage of steam where the packing ring is cut through; *e f* in the section and plan show the body of the piston, *i j* the junk ring, and the aperture for the extremity of the piston-rod. The junk ring has for its office to hold the packing

ring in position, and it is attached to the body of the piston by means of bolts. The plan is taken with the junk ring removed, in order to show the packing ring in plan. It will

FIG. 68.



be observed that this packing ring is not concentric, that is to say, it is not of equal thickness throughout, being made thinnest at the point where it is cut through, and increasing in thickness both ways to a point diametrically opposite, the object being that the packing ring may press equally upon the cylinder at every part of its periphery. This ring is usually made of cast-iron, which exhibits a very uniform

elasticity. The description of the piston being completed, it is necessary to explain the method of manufacturing it.

The first step should consist in boring out the aperture *k*, after which a rod may be fitted into it; then the piston is, by means of this rod, suspended between the lathe centres, and its body is accurately turned, and drilled and tapped to receive the junk ring bolts. The upper surface of the flange of the piston being scraped and faced to fit the packing ring, and the lower surface of the junk ring being treated in a similar manner, the upper and lower edges of the tongue piece are also fitted by scraping to the surfaces with which they are in contact. There are two ways of making the packing ring; it may be turned in the lathe to a diameter a little greater than that of the cylinder, when the following means will be required to introduce it into the same. An iron hoop, cut on one side and furnished with lugs, as shown at *m*, is placed around the piston so as to embrace about half the depth of the packing ring, as shown by the dotted lines at *g h*. It is then screwed up by means of the bolt and nut shown at *n*, until the packing ring is sufficiently compressed to partly enter the cylinder; the ring *m* may then be removed, as it is evident that the cylinder embracing the packing ring will effectually prevent its expansion. The piston may then be forced completely into the cylinder. A method used occasionally, consists in turning the ring accurately to the diameter of the cylinder, then hammering it on the internal periphery, to render it hard and elastic, and to impart to it a sufficient degree of tension, so that when it is subsequently cut, it may expand and press against the sides of the cylinder. This ring must of course be inserted in the same manner as the last.

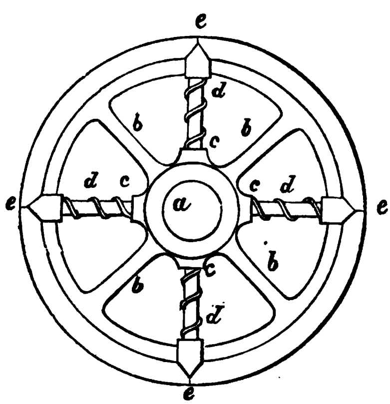
The above may be considered a general description of the most ordinary kind of piston. It will be necessary next to describe some varieties of steam pistons. The first approaches very nearly in principle to that already described; it is furnished with a cut ring precisely similar to that already described, but this ring does not press immediately upon the internal surface of the cylinder, but it acts upon rings external to it, which are thus urged against the interior of the cylinder. These outer rings are usually made in three or more segments, so as to adapt themselves as nearly as possible to the form and variations of form

of the cylinder. In the construction of this piston, the method followed is similar to that already detailed, which may, in fact, be regarded as the general method of constructing steam pistons, the modifications in each case being obvious.

Large pistons are not constructed with solid bodies, but they are hollowed out, presenting in horizontal section the appearance of a wheel, as it consists of a boss through which the extremity of the piston-rod passes, which boss is connected with the periphery of the piston by means of plates, top and bottom, and arms which run from the boss to the periphery.

Among the means which have from time to time been proposed for packing pistons, the action of a great variety has been made to depend upon the action of spiral springs, which press outwards from the boss of the piston to the periphery; in the form these springs are caused to act upon wedges, which being urged outwards, tend to force apart the segments. The accompanying Fig. 69, will give some idea of the arrangement of a

Fig. 69.



piston upon this principle: *a* is the aperture in the boss of the piston, through which the extremity of the piston-rod passes, and in which it is secured. This boss is connected with the periphery of the piston, and with the bottom of the same by the arms *b b*; *c c c c* are four stops, against which the extremities of the spiral springs abut; the springs *d d d d* are guided by rods passing through their axes for a portion of their length; the

springs act upon wedges *e e e e*, which, in being pressed outwards, necessarily tend to separate the four segments into which the external packing-ring is divided. This piston has not come into general use, being attended with many disadvantages, one of which is to wear the cylinder irregularly. They are also inconvenient on account of their complicated form.

Pistons are not unfrequently packed with large cut rings, or segments, which are urged against the cylinder by small blade-springs, placed between the body of the piston and the packing ring. In some cases, these springs have been supported by arms proceeding from the centre of the piston instead of abutting against the periphery, which periphery is, in the present case, dispensed with. The arrangement of this piston is the shown Fig. 70 ; *a* is, as before, the aperture for the piston-rod, *b c d* a cut packing-ring, *e e e e* four arms, which serve a double purpose, connecting the boss with the top and bottom of the piston, and carrying at their extremities the blade-springs *f f f f*. These springs press outwards against the cut ring *a b c*, which is cut at *b*; these springs may, by set screws, be adjusted to exert any

FIG. 70.

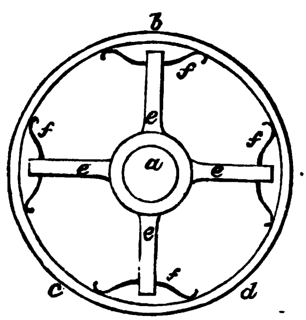
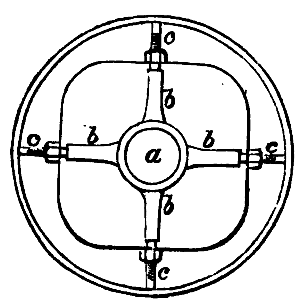


FIG. 71.



required pressure upon the packing-ring. This arrangement appears, however, too fanciful for practical purposes, and it has not come into general use.

Another form of piston has been proposed, which is shown, Fig. 71. This is furnished with a cut ring; *a* is the aperture for the piston-rod, *b b b b* are arms, *c c c c* is an elastic ring, which is distorted, as shown by the set screws, which set screws working in nuts attached to the ring, abut at their further extremities

upon the cut ring, and as the distorted elastic ring tends to regain its circular form, the set screws are pressed against the packing ring. This piston, like the previous one, possesses the disadvantage of being complicated.

In another form of piston, an elastic ring is also used, but in this case it is compressed by one set screw only. None of these forms, however, have, as yet, superseded the first piston which we described.

Before taking leave of the subject of steam pistons, we must call the reader's attention to the section shown, Fig. 72: *a b c* are three cut rings, precisely similar in their mode of action to the ordinary ring described at the commencement of the chapter,

FIG. 72.

d is the aperture in which the piston-rod is fixed, *e e* show the general body of the piston; the packing rings are made very narrow, about a quarter of an inch wide, several of them being used. These rings are each placed in a separate groove. This piston is certainly the most simple in construction that we have yet seen; it has been applied with considerable success to locomotive engines.

The next element to be considered is the piston-rod, which, however, from the extreme simplicity of its form, will require but a short notice; it is usually made of wrought-iron, and accurately turned in the lathe. To the top of this piston-rod various kinds of cross-heads are attached, according to the class of engine for which it is designed.

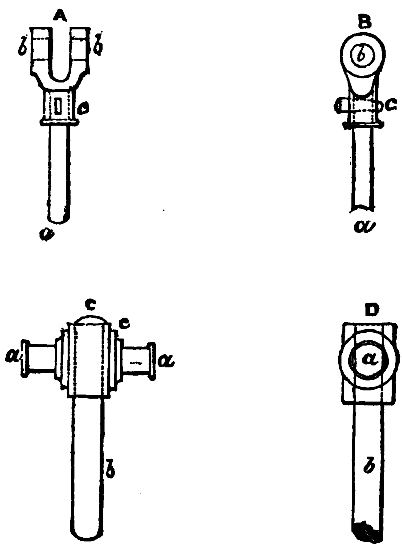
To calculate the diameter of the piston-rod, we have the following formula. Let p be the maximum pressure of steam per square inch, d, diameter of cylinder in inches, D, diameter of piston-rod in inches; then

$$D = \frac{d}{55}\sqrt{p}$$

For low-pressure engines, where the total pressure does not exceed 30 lbs. per square inch, the diameter of the piston-rod may be made equal to one-tenth that of the cylinder.

It now remains to describe the various kinds of cross-heads commonly used with the piston-rods of steam-engines. Some of these are shown in Fig. 73. A B are elevations of a cross-head commonly used when the piston-rod is immediately jointed to the connecting-rod. In the sketches, *a* shows the extremity of the

Fig. 73.

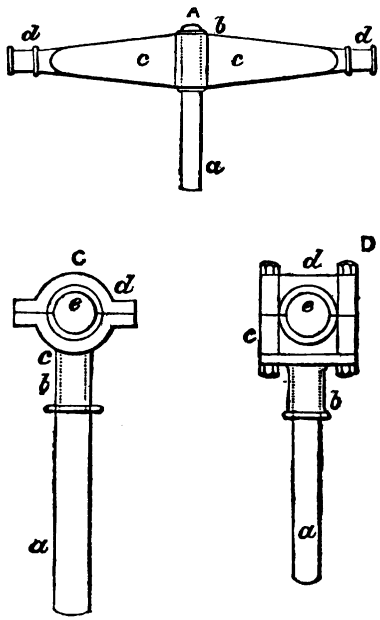


piston-rod, which is passed into the tubular part, *c*, of the cross-head, where it is firmly fixed; above this, the cross-head is forked, in order to admit the extremity of the connecting-rod, and the forked ends have cylindrical apertures, *b*, bored through them to receive the pin, which joins the piston-rod to the connecting-rod. C and D are elevations of a cross-head used with beam engines; the part *c* is perforated and traversed by the extremity of the piston-rod, *b*; *a a* are gudgeons, which carry the extremities of links connecting the piston-rod with the main beam. When no links are used, as in the case of the half-beam engine, either the end of the beam or the cross-head may be forked, a moveable pin being used.

At Fig. 74, A is an elevation of a cross-head used for side lever engines; *a* is the extremity of the piston-rod, which is passed into tha perforation, *b*, of the cross-head; *c c* are the two arms of the

cross-head, and *d d* two gudgeons which carry the extremities of links, which descend to the side levers or beams placed upon each side of the steam cylinder. C and D show two kinds of cross-heads used when the piston-rod is jointed direct on to the crank, as is the case in oscillating engines. *a* is the piston-rod, *b* the perforated part of the cross-head *c* and *d*, plummer-block and cap

FIG. 74.



of the cross-head, *e* aperture for crank-pin, which is surrounded by brass bearings as shown. The cross-heads are joined, where necessary, by bolts. The plummer-block and cap of C are frequently made of gun-metal, when no brass bearings will be required.

In the former figure, C is very similar to a kind of cross-head used in some kinds of locomotive and other engines. The square part of the cross-head is provided with small ridges or guides, as shown by the dotted lines, parallel to the piston-rod; this block moves between accurately formed guides, and the protruding journals, *a a*, carry the ends of a forked connecting-rod. This cross-head is sometimes placed at the extremity of the piston-

rod, and sometimes elsewhere; the square part is called the guide-block.

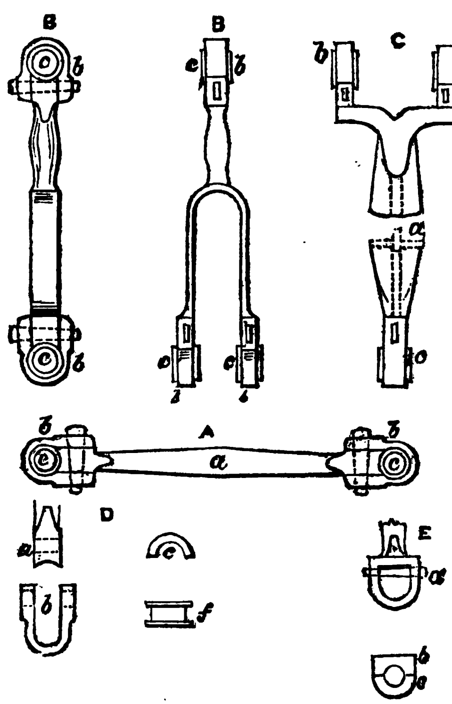
The cross-head shown at *a* generally has the connecting-rod pin prolonged, guiding blocks being carried at its extremities, which move between suitable guides.

These are the general forms of cross-heads, and with regard to their construction, we may make the following brief remarks. Whenever it is convenient, they should be of wrought-iron, and all the round parts must be turned, the flat ones planed, and the bearings, whether sliding or revolving, accurately fitted to each other, by scraping in the usual manner. Those parts which are of irregular form must be brought up to a bright surface, by means of files of suitable forms.

Having completed the descriptions of cross-heads, connecting-rods and parallel motion links will next occupy our attention. We will first describe the former class of elements.

A, Fig. 75, shows a form of connecting-rod, commonly used

Fig. 75.



for engines, where the piston-rod is joined on to the connecting-rod; it consists of a spindle *a*, having at each end bearings *b b*, retained in position by straps fixed by wedges and keys passing through them, and through the extremities of the spindle. Of these straps and bearings, we will, however, speak subsequently. B shows a connecting-rod of the forked description, as used with the single guide block. This is also furnished with bearings similar to those last described.

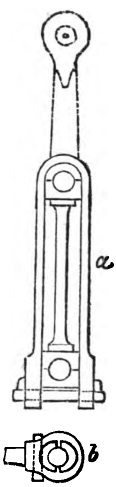
C shows an elevation of a connecting-rod, frequently used for beam engines; it is broken off to save length, the upper and lower extremities only being shown. *a* is a round spindle for wrought-iron, but of an × section as shown, by the dotted lines for cast-iron. At *b b* are two bearings, similar to those already mentioned, which embrace the journals of a pin in the main-beam; *c* is the crank pin bearing, and is of peculiar form, presently to be described. D shows bearings of the first class, *a* being the end of the connecting-rod, *b* the straps, *c f* elevation and plan of brass bearings. E shows the second kind of bearing as mentioned in connexion with the beam-engine connecting-rod; *a* is the extremity of the connecting-rod, into which bearings *b* and *c* are placed, after which they are passed over the crank pin, and tightened up by the wedge dotted at *a*.

With regard to the construction of connecting-rods, there is but little to be said. Wrought-iron is the best material to use for their formation. The parts may be wrought in the same manner as that described for the cross-heads; all the bearings should be of brass or gun-metal, and must be accurately fitted to the gudgeons on which they play. The method of connecting them to the other elements will be mentioned hereafter.

We have now to consider the construction of links for parallel motions, &c. Many of them are precisely similar in general form to those already described; some have, however, different forms, as shown, Fig. 76. *a* may be said to consist of a long strap, into which two sets of bearings, furnished with ridges to guide them, are placed and keyed up tight, being retained at their proper distances by means of a strut or distance piece, as shown. *b* shows the extremity of a link which is bored out at the end larger than the bearings which are inserted, placed around the journal, on which they are intended to work, and keyed up tight.

The construction of links is identical in its details with that of connecting-rods. Before concluding the subject, it may be desirable to mention the fact, that links requiring three bearings are frequently made as a combination of the two forms illustrated above, the complete link being surmounted by a bearing extremity, as shown by the dotted lines.

Fig. 76.

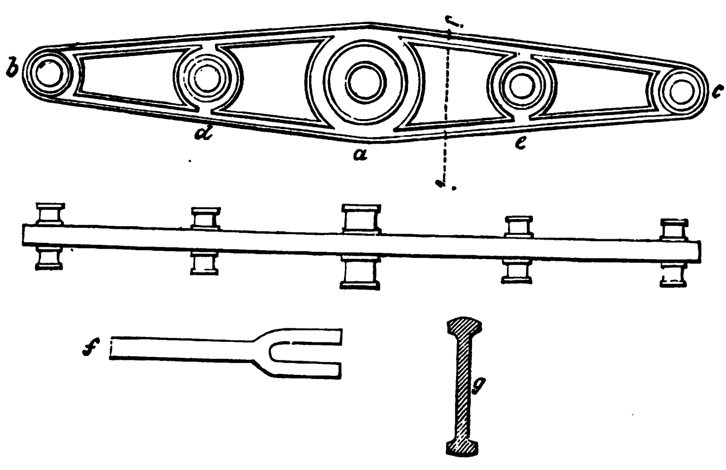


The next subject to be mentioned, consists of parallel motions, one class of which consists of elements already described, another also has been mentioned, which consists merely of guides between which slide-blocks move in a rectilineal direction, having a reciprocating motion.

Another method, which is attended by results of a very satisfactory character, consists in prolonging the piston-rod beyond the cross-head, and carrying its extremity in a piece of metal, bored out cylindrically to such a diameter as to allow it to move freely within it. When this method is employed, the piston-rod should be made somewhat stronger than usual, as it will then have to sustain the stress due to the varying angularity of the connecting-rod.

The beam next requires attention. It is an element simple in

Fig. 77.



its form, and will require but little description. An elevation of an ordinary beam is shown Fig. 77. *a* is a gudgeon, upon which the beam is supported; *b* that to which the piston rod is attached; *c* that carrying the connecting-rod; *d* and *e* are other gudgeons, which serve for the support of pump-rods, &c. Beneath the elevation is shown a plan of the beam.

This beam will be used with a forked connecting-rod, &c.; but at *f* is shown a plan of the end of a forked beam, such as is used in side lever and grasshopper engines. At *g* is shown a section of the beam, taken through *i j*.

The proportions generally adopted where no special circumstances prevent their employment, are, for the various elements now described, as follows:—

The stroke of the piston should be twice the diameter of the cylinder to get the least cooling surface of steam cylinder. The beam should be three times the length of the stroke, and its depth at centre should be equal to the diameter of the cylinder. The connecting-rod should be from twice to thrice the length of the stroke.

The rule to calculate the thickness of the beam at the centre will be as follows:—

Let p = maximum pressure per square inch on the piston, D = diameter of cylinder in inches, d = depth of beam in inches, l = length of half beam in feet, t = thickness in inches. Then

$$t = 0{\cdot}02.\,p\,l\left\{\frac{D}{d}\right\}^2$$

but if the foregoing proportions be used,

$$D = d$$

hence

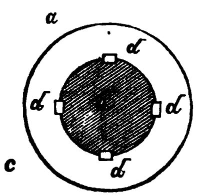
$$t = 0{\cdot}02\,p\,l$$

The method of applying this calculation to half beams is obvious, for we have only to take for the value of l the distance between the centres of the gudgeon, which carries the top of the piston-rod, and that by which the connecting-rod is carried.

The beam is usually made of cast-iron, and the manipulations to which it is subject after leaving the foundry are not of a very extensive character, for all that remains to be done consists in

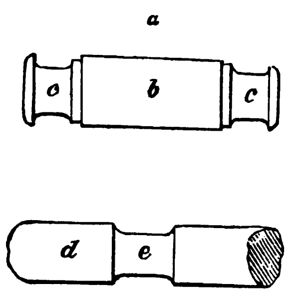
boring the apertures to receive the gudgeons, and fitting the latter to the beam. A favourable opportunity now offers itself to consider the means employed for fixing cylindrical elements to cylindrical apertures, when it is necessary that they be incapable of movement. Fig. 78 shows a section of shaft upon which it is required to fix a cylindrical band or boss immovably; *e* is the shaft, and *a b c* is the boss.. It is bored to fit with accuracy the shaft which has been previously turned, and in both the boss and the shaft certain slots are made to admit keys *d d d d*, which keys prevent the shaft from revolving within the boss. The method now described is that generally used for fixing the gudgeons of beam-engines. There are other methods of fixing bosses upon shafts, but these will subsequently be mentioned.

Fig. 78.



The form of these pins or gudgeons, and in fact of journals generally, now requires attention. In Fig. 79 *a* represents an elevation of a gudgeon for a beam. The central part *b* does not in every case require to be turned; but the journals *c c* must be accurately brought to the required form; *d* represents the general form of journals. The part *e* must be accurately turned, as it will work in contact with the bearings. The other parts of the shaft are also turned, although accuracy of form is not necessary on the general surface.

Fig. 79.

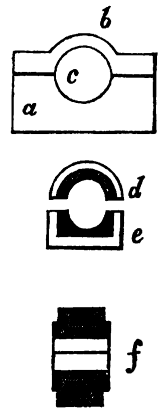


The next matter to be considered is the form of bearings generally, and these are shown in Fig. 80.

a is a solid block of cast-iron, having on its upper side a rectangular notch or recess: it is called a plummer block. This is surmounted by a cast-iron cap *b*, having in its lower surface a semicircular notch. The two are connected by bolts, as shown. The general form of this arrangement will at once be recognised from the general resemblance which it bears to some forms of piston-rod cross-heads. Between the plummer block and cap,

brass or gun-metal bearings are placed, of which sections are shown at *d* and *e*, *e* is first placed in the plummer block, *d* is placed upon it, and then the cap *b* is bolted down to the plummer block. The bearings are furnished with flanges, to prevent their sliding away from their proper position. At *f* is shown a vertical section through the plummer blocks and bearings, which shows the general arrangement. The bearings are usually bored out accurately, and subsequently fitted to the journals, which they are intended to sustain, by scraping.

Fig. 80.

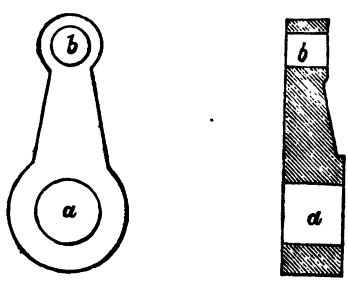


Various forms of plummer blocks and bearings are used, but the one described will convey a general idea of the principle involved in their construction.

Next to the beam comes the connecting-rod; but the various forms of this element have already been considered.

The crank now requires attention, with regard to general form and construction; the theory of its action having been already treated. Fig. 81 shows the general form of one class of cranks, viz., those which are not made in the piece with the crank shaft. It is desirable to use this form whenever it is available for small engines. Cast-iron cranks

Fig. 81.



are not unfrequently used, but wrought-iron is certainly preferable, and no other material should be allowed in the construction of engines of considerable size. Cranks for inferior purposes are very frequently made by bending the crank shaft to the required form; but this method does not yield results of so satisfactory a

character as that which consists in forging upon the crank shaft a solid projection, and subsequently cutting out the aperture of the crank.

When separate cranks are used they must be planed on the surfaces, and then bored accurately to receive the shaft and the crank pin. In the figure, *a* shows the aperture for the shaft, and *b* that for the crank pin. In fixing cranks upon the crank shaft, keys will be found advantageous; but it is also advisable to employ the method known as shrinking on, which consists in heating the crank boss until it will just pass into its position, having been originally bored out to a diameter somewhat less than that of the shaft on which it is to be fixed. Then it is placed upon the shaft in the required position, and allowed to cool, whereupon it takes a firm grip of the shaft.

The next element to which the reader's attention will be called is the crank shaft or main shaft of the engine, and the first step towards the construction of the same will consist in calculating its diameter, which may be effected by the following formula:—

Let d = diameter of shaft in inches.

H = horse-power of engine, calculated for the maximum pressure.

N = number of revolutions per minute performed by the engine.

Then the diameter may be found from the equation—

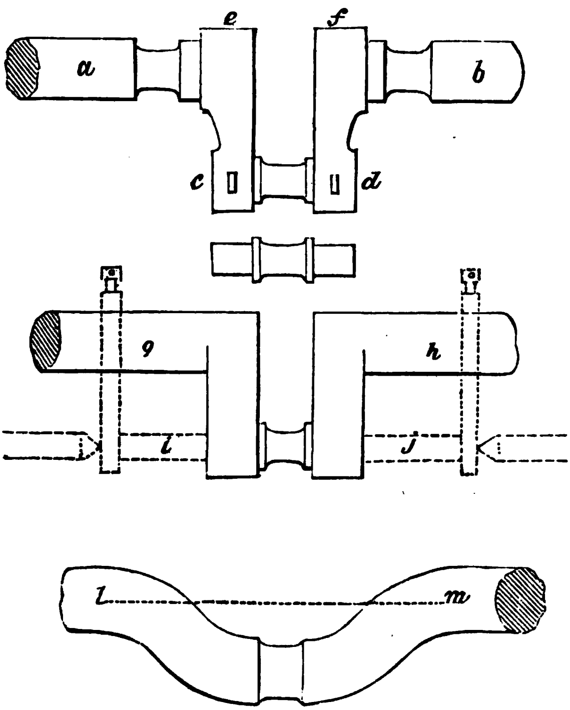
$$d = \sqrt[3]{\frac{320\ H}{N}}$$

This calculation applies, of course, to the smallest part of the shaft, which will generally be the journal. The general form of the crank shaft may now be described. In Fig. 82 three forms of crank shaft are shown, and the first form will also serve to illustrate another arrangement.

a b, Fig. 82, shows two portions of a crank shaft, fitted with two crank, *e c*, *f d*, carrying a crank pin, *c d*. Close behind the cranks journals are turned upon the shafts, which rest in the shaft bearings. Beneath is shown the form of the crank pin, which may be secured by wedges driven through the small bosses of the cranks. If we conceive the part *d f b* to be removed, then will *a e c* represent the arrangement used in engines having but one

crank. *g i j h* represents a crank shaft having the crank forged in one piece with it, and *l m* shows a shaft where the crank is forged upon it; but instead of having vertical arms, as in the last case, they are curved.

Fig. 82.



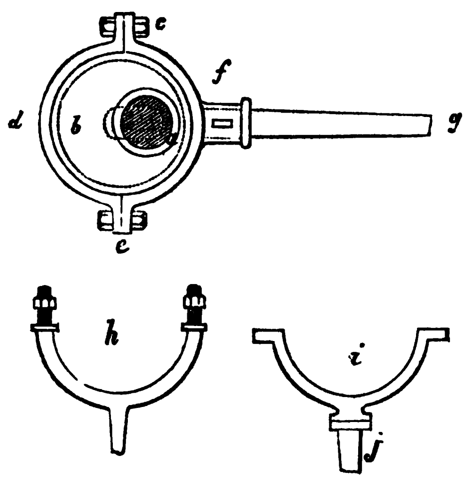
With regard to the construction of the crank shaft, we may observe that it is usual to bring it up to a bright surface, turning those parts which admit of such treatment, and planing and filing others. In turning the crank pins in such arrangements as those shown by *g h*, some particular method of centring the shaft must be adopted. The dotted lines at each extremity show carriers, in which centres are made in a line with the axis of the crank pin, and between these centres the work is supported in the lathe, the carriers being properly blocked to retain them in the proper positions.

The bearings of the crank shaft are usually of the form already

described when treating of those employed for the support of the working beam.

Those elements which are carried by the main shaft will next require attention, and the first which occurs after the crank is, generally speaking, the eccentric. This consists of a wheel or pulley of a truly circular form, but fixed upon the shaft eccentrically to it; and it may be supposed to be produced by increasing the dimensions of an ordinary crank pin until they arrive to such a point as to extend in every direction beyond the main shaft. Fig. 83 illustrates the arrangement of the eccentric.

Fig. 83.



a is the main shaft to which the eccentric is keyed; *b* is the eccentric sheave, on the edge of which is a groove to receive a band, within which the eccentric sheave may revolve. This band corresponds with the cross-head of the piston-rod when that is jointed directly on to the crank pin. The band is made in two parts, *c d e* and *e f c*, which are connected with bolts at *c* and *e*. At *f* is a socket to receive the extremity of the eccentric rod, which is firmly keyed therein. This is the arrangement generally used with gun-metal straps. Sometimes, however, it is found expedient to make both sides of the strap of the same form as *c d e*, and in this case the eccentric rod is forked, as shown at *h*, and the extremity of each fork is screwed after the manner of a bolt,

so that the screwed ends, being passed through the bolt holes at *c* and *e* and furnished with nuts, supply at once the means of connecting the two halves of the strap with each other and with the eccentric rod.

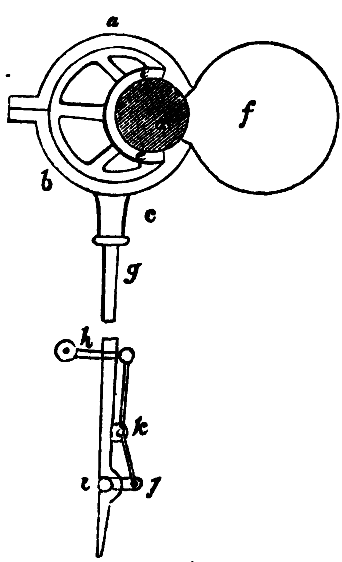
It frequently happens that instead of gun-metal straps others, formed of wrought-iron, are employed, and in this case the eccentric rod may be forged in one piece with the half of the strap. In other cases, however, one half of the strap is made as shown at *i*, the extremity of the connecting-rod being of the form shown at *j*, so as to admit of its being being bolted to the eccentric strap.

The eccentric rod may be jointed direct on to the slide valve rod, or on to an arm attached to a shaft carrying another arm, from which a slide valve is worked.

As it is necessary that a certain advance be given to the eccentric over the crank, in order to ensure the direction of the engine's motion, some peculiar arrangement must be provided in those engines which occasionally require to be reversed.

There are two forms of reversing gear in common use: one generally employed for paddle-wheel engines, and the other for

Fig. 84.



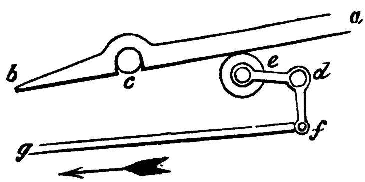
screw-propeller and locomotive engines; the former, however, shall be first described.

Fig. 84 represents the ordinary single eccentric reversing arrangement. In this case the eccentric is not keyed on to the shaft, but so arranged that the latter is capable of revolving free within it. *a b c* is the eccentric, which, in order to prevent its falling to the bottom of the stroke by its own weight, is counterbalanced by the weight *f*, so that the eccentric may remain in any position while the shaft revolves. Upon the shaft is bolted a segmental collar *e e*, either extremity of which coming in contact with the inner part of the balance weight *f*, which is bolted to the eccentric, will propel the latter. If we suppose the engine to be stopped, and the slides moved by hand to such a position as will cause the engine to start in a direction contrary to that in which it was running, the segment at collar *e* will retire from the balance weight on one side, and having performed a portion of a revolution, will come in contact with it on the other side, and cause the eccentric to revolve with the shaft; after which the motion of the engine will continue uniform until some further adjustment is made.

It is, however, necessary to provide some means whereby the eccentric rod may be temporarily disconnected from the slide valve gear, in order that the latter may be moved by hand to the position necessary to reverse the motion of the engine. The lower part of the eccentric rod arranged for this purpose is shown at *h i*. At *i* is a pin attached to a lever acting on a way shaft to which the limbs by which the slide is moved are attached. This pin gears in a notch or gab in the extremity of the eccentric rod, which is called the gab lever. Behind this pin the gab lever is perforated, and a strip of metal inserted as shown at *l*. Now it is evident that if this strip of metal be forced forward, it will fill up the notch, forcing the pin out of it, thereby disengaging the valves; nor will the pin be able to re-enter the notch until the strip of metal is withdrawn. All that is now required is the means of acting this strip of metal, and such means are furnished by the lever shown. It is fixed on a fulcrum at *k*; the lower extremity is attached to the strip of metal, and the upper one to a handle *h*, which passes through the gab lever. It is evident that by pushing the handle towards the gab lever the

engines are thrown out of gear; whereas by pulling the handle from the gab lever, the engines are allowed to fall into gear. Some means must of course be provided to retain the handle *h* in position, but these are obvious. It is evident that the sliding piece may be made in one with the lever, instead of being jointed to it as we have described. In some cases the stop is dispensed with, and the gab lever is raised when necessary by means which may be rendered more clear by Fig. 85. *a b* is the gab lever,

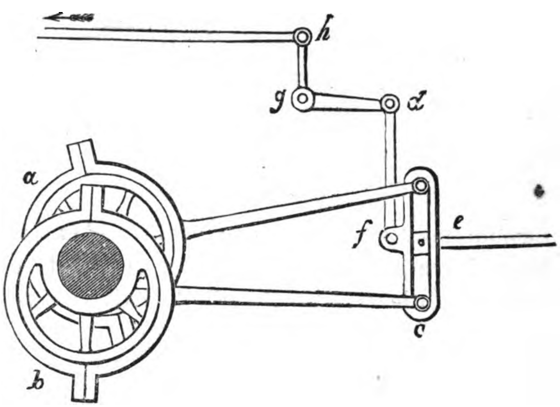
FIG. 85.



c the pin communicating with the slide valves, *d* is a short shaft on which is an arm, *d e*, carrying at the extremity *e* a pulley close under the gab lever. To the short shaft is also attached an arm, *d f*, having a link, part of which is shown at *f*, attached to it. Now it is evident that by moving the link *g f* in the direction indicated by the arrow, the gab lever will be raised clear of the pin *c*. The other class of reversing gear now requires attention. The arrangement already described is evidently inappropriate to locomotive and other high speed engines, as it would rapidly be destroyed by the vibratory action, even if it were possible to work with it. Hence, in engines of this class we find that two eccentrics have generally been used, one for the forward motion and one for the backward motion, either of the eccentrics being capable of being put into gear with the valves. In the first instance the extremities of the eccentric rods were furnished with forks, which, by an ingenious but complicated arrangement, were worked to gear with the slide in such a manner that when one fork was in gear the other was out, so that either eccentric could be brought into action, according to circumstances. This arrangement has, however, been long since superseded by that beautiful contrivance known as the link motion, which will now be described with the assistance of Fig. 86.

Let *a* be the forward eccentric, that is to say, the eccentric which is set to give the engine a forward motion, and let *b* be the backward eccentric. The lower extremities of the eccentric rod are attached to a link, *c d*, within which is a block connected with a slide rod, *e*. To the back of the link is attached an eye, *f*, from which a link proceeds to the end, *d*, of an arm, carried by a short shaft, *g*, which shaft has also an arm, *g h*; and to the extremity, *h*,

Fig. 86.

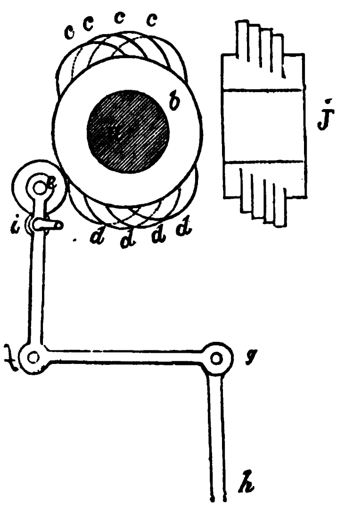


is attached a link as shown. Now it is evident that by moving this link in the direction of the arrow, the link *c d* will be raised, and sliding over the block attached to the slide rod the latter will be brought under the control of the eccentric *b*. By a reverse method it will be brought under the action of the eccentric *a*. It is not necessary that the block should be quite at the end of the link, but it may be at some intermediate point, and by adjusting this position the quantity of steam admitted to the cylinder is also adjusted.

In some cases the link *c d* is suspended from a fixed point, and a connecting-rod is then jointed to the slide-rod, and the extremity of this connecting-rod is attached to a movable link, *d f*. This arrangement, known as the link motion, is in the locomotive engine worked by a hand lever, but in screw engines it is very commonly regulated by a hand wheel. Having disposed of the eccentric whereby the slide valve is worked, a description of the

means of working the expansion valve is necessary. This is effected by means of cams, of which the arrangement is shown Fig. 87. *a* is the main shaft, *b* the boss upon which various cambers are placed side by side, in positions corresponding to the points at which it may be required to cut off the steam; *e* is a roller which rests against any one of the cams, as may be required;

FIG. 87.



it is carried at the extremity of an arm attached to a short shaft, *f*. The roller will, twice during every revolution, that is, once in every stroke of the engine, be forced back by the cam, whereby the link *g h* will be raised, and the expansion valve shut. The roller is moved horizontally to bring it under the action of any cam by means of a screw worked by a handle eye, which screw carries a fork or guide, embracing the pulley *e*. Of course the pulley must only be shifted when resting on the plain part of the boss *b*. Another view of the expansion cam arrangement, showing the edges of the cambers, is seen at *j*.

With regard to the construction of eccentrics and cams, it only remains to be observed that the moving parts must be very accurately fitted to each other by the usual means, and the other parts, with the exception of the sides of the eccentrics, be

brought up to bright surfaces by turning, planing, and filing. With regard to the construction of the fly-wheel there is but little to be said. It is usually of cast-iron, in one or more pieces, according to circumstances. It is bored out accurately, and firmly keyed on to the crank shaft, and if very heavy it should have bearings to the shaft on each side. We have known cases in which the fly-wheel was retained in position by a screw running through the boss of the wheel into the shaft; but this is a clumsy arrangement, and may give rise to much difficulty if it is required at any time to remove the fly-wheel from the shaft.

It is very advantageous in many cases to make the wheel with a cast-iron boss or rim, and with wrought-iron arms, which may readily be done by imbedding bars of wrought-iron in the mould previous to casting the metal, which will then envelope the extremities of the arm, and in cooling it will firmly grip them, and the hold may be increased by notching the extremities of the arms, previous to placing them in the mould.

Those elements called governors next require attention, and of these a very great variety have been produced; they may, however, be arranged under two heads, viz., those which have for their principle the equilibrium of the force generated by the velocity of the engine with some external force, and those which regulate the admission of steam in proportion to the resistance which the engine has to overcome. In the first class we have the conical pendulum or common two-ball governor, in which the centrifugal force is balanced by the attraction of gravitation; we have also in this class other varieties, some with two and some with four balls, in which the centrifugal force is resisted by the elasticity of a helical spring, and among these Silver's four-ball marine engine governor stands forth preeminently for practical utility.

Plate XII. represents a number of governors to which our attention has been lately directed especially in order to determine the relative values, or rather the relative delicacies of various kinds. Fig. 1 represents the commonest form of governor, which consists of two balls, so arranged that at a given velocity the amount of steam admitted to the engine is, upon certain data, sufficient for the work it has to perform; it is, however, no difficult matter

to show that this arrangement, in common with others of the first class, gives results far from accurate. For instance, let us suppose that an engine is supplied with steam of uniform pressure, and that it is working at a certain given velocity, which velocity it is required to maintain, with very slight variations. Let us suppose that the engines to which we refer are employed to drive the machinery in the works of a mechanical engineer; then they will be subject to constant variation of work to be done, and if it is imagined that some extra machine, say, a circular saw, is thrown into gear with the engine, more power will be required to do the work of the establishment; hence the steam pipe must afford a wider passage to the steam, which of course cannot be done but by opening wider the valve which is controlled by the governor. Thus, for instance, to take an example, if we require one-tenth more power, we must absorb an equal additional quantity of steam, or the valve must be opened so as to give so much more area of steam passage, the amount of friction on the sides of the steam passage being, on this occasion, omitted. It is unnecessary to encumber our space with the exact calculation of this matter, but it is very simple, requiring only the most elementary principles of plane trigonometry for its solution, hence we feel justified in omitting it. We may, however, observe, that the width at any point of real steam passage will vary very nearly as the verse sine of the angle described by the valve from the position at which the steam is shut off, and this verse sine will vary but slightly for considerable angular variation, until the angle described amounts to about 45°; hence when the throttle valve is but slightly open, and any considerable amount of extra work is thrown upon the engine, a very considerable angular deviation of the throttle valve will be requisite in order to afford sufficient area of steam way, and to obtain such deviation the governors must of necessity collapse to a notable extent, and remain in such position, for the maintenance of which a reduced velocity of the engine is indispensable.

Fig. 2 represents a form of governor in which the elastic resistance of a spring is employed in the place of gravity; hence this apparatus may be used in positions deviating from the vertical,

or in other words, the plane of revolution of the balls need not necessarily be horizontal, which position is the only one in which the common governor is efficient.

Similar in action to the last described governor is Silver's marine governor, but the disturbing effects produced by variation of position, are still further obviated by the employment of four balls instead of two.

Figs. 3 and 4 are illustrative of governors, in which the centrifugal force is, as in the last case, opposed by the elasticity of the spring, but these forms have been illustrated for the purpose of comparing them with each other; for although at the first glance it may appear very different, yet they are but modifications of one form, being identical in principle. In Fig. 3 we have the balls attached to the ends of bent levers, *a a*, to the other extremities of which are jointed links, *a b*, attached to a sliding collar, *b b*, which is in connexion with a spiral spring placed around the main spindle of the governor *c c* are the fulcra of the bent levers. Now it is evident that we may alter the angle *a c a* without destroying the principle of the apparatus. Let us suppose that the two arms of the bent lever are made parallel and of equal length, then we arrive at the form shown Fig. 4, which also presents many points of similarity with the form shown at Fig. 2, and it remains for us to determine which is the more delicate, that is to say, in which governor the greatest effect upon the valve will be produced by a given degree of variation of velocity.

In order to satisfy ourselves on this point, it is not necessary to have recourse to intricate methods of analysis, for it is a matter of observation that in Fig. 3 the balls must become horizontal before they can cease to have further effect upon the spring; or in other words, so long as the centrifugal governor can be used, the desired effect will be produced by this form; whereas in the form shown in Fig. 4, as soon as the arms of the governor have risen to an angle of about 40 degrees to the horizon further action becomes impossible, as the links *a b* will then permit of no further separation of the balls; and the delicacy of this apparatus in every position is equally inferior to that of the arrangement illustrated in Fig. 3.

The foregoing examples of the first class of governors illus-

trate the principles of a great variety, but it would be useless to attempt to give any complete account of all the various forms which have been brought forward; we may, however, observe, that in some instances the resistance which is afforded by gravity or helical springs, in the cases described above, is supplied by the resistance of the atmosphere to revolving vanes, or by the resistance of a fluid to vanes, or to a screw revolving in it.

Figs. 5 and 6 are illustrative of a governor of the second class, Fig. 5 being a plan of the arrangement, and Fig. 6 a side elevation of a portion of the same. This contrivance adjusts the quantity of steam admitted to the engine to the power to be exerted; its arrangements and action are as follows. In the illustrations, *a* represents a bevel-wheel, to which the power of the prime mover is, in the first instance, transmitted; *c* is another bevel-wheel attached to the shaft, from which the power is transmitted to the machinery to be driven, a third bevel-wheel, *b*, serving to connect the two former ones, *a* and *c*. The wheel *b* runs loose upon the turned extremity of a lever, *b e*, which has its fulcrum at *d* in a line with the axis of the main and working shafts, so that the wheel *b* may revolve about the centre *d*, without being thrown out of gear with *a* and *c*. To the extremity *e* of the lever *b e*, is attached a rod, carrying at its lower extremity a piston fitted to work air-tight in a cylinder, *f*; the upper part of this cylinder is closed, containing condensed air. Let us now suppose that the wheel *a* is caused to revolve in the direction indicated by the arrow, then it is evident that if the resistance offered to the revolution of the wheel *c*, be greater than that offered to the revolution of the wheel *b* about the centre *d*, then will the latter take place, the wheel *b* descending; but in so doing it will necessarily raise the extremity *e* of the lever *e b*, and with it the piston in the cylinder *f*, by which the air above the piston will be still further compressed, so that a continually increasing resistance will be offered to the descent of the wheel *b*, and at length the point will be arrived at where its position with regard to the centre *d* remains unaltered, the motion imparted to it by the wheel *a* being transmitted to that at *c* on the working shaft, and the elevation or depression of the wheel *b* will thus be in proportion to the resistance offered by the machinery to be driven. The lever *e b* is so connected with the throttle valve of

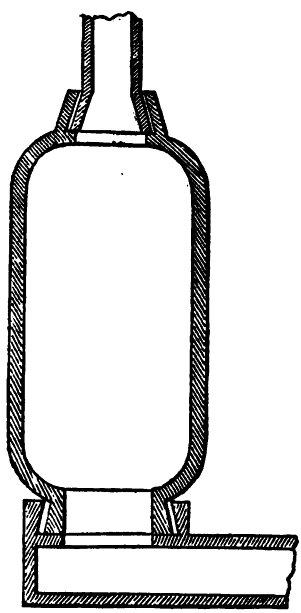
the engine, that the greater the elevation of the piston in the cylinder *f*, the greater will be the quantity of steam admitted to the working cylinder of one engine, and *vice versâ;* hence the greater the resistance to be overcome, the greater will be the quantity of steam admitted to the engine, so that the velocity may remain uniform. The compressed air in the upper part of the cylinder *f*, may of course be replaced, if deemed desirable, by a spring. If when the engine is running, an extra load be thrown upon the working shaft, the wheel *b* descends until the resistance offered to its descent is again equivalent to the work to be done, and in so doing the throttle valve is opened to a greater extent than before; but if, on the contrary, a portion of the work be thrown off, the pressure of the air in the cylinder *f* presses down the piston, and raises the wheel *b* until the opposing forces are again in equilibrio, the throttle valve being thereby partially closed. It is of course necessary in the first instance to adjust the opening of the valve for some given position of the governor, and this is done by means of a right and left-handed nut, which governs the length of one of the links connecting the governor and the throttle valve. No special remarks are requisite as to the construction of governors, beyond the observation that the parts must be very accurately fitted together by means of the processes already set forth.

Let us now proceed to the description of the vessels employed for condensation of the steam after it has done its work in the cylinder of the condensing engine. These condensers are of two classes; first those in which the steam is condensed by water, and secondly those in which it is condensed by contact with cold metallic surfaces, these latter constituting what are termed surface condensers.

The apparatus used for effecting the condensation of the exhaust steam by the first method is usually exceedingly simple, consisting of a cylindrical vessel; or if this form be not convenient, any other may be adopted according to the requirements of the engine to which it is intended to attach the condenser, within which vessel is placed a perforated jet rose or tube connected with the exterior of the condenser by means of a pipe passing through the side of the same, and furnished with a cock to afford a means of regulating the admission of water to the condenser.

The action of this arrangement is as follows. Before starting the engine, a tank, in which the condenser is fixed, is filled with cold water, and subsequently kept full; steam is then admitted to the condenser to expel the air which formerly filled it, which it does either through a conical valve placed at the top of the condenser, called a snifting valve, or otherwise through a valve at the foot leading to the air-pump. As soon as all the air is displaced, the cock attached to the pipe which terminates within the condenser is opened, and water flows into the condensing vessel, where it comes in contact with the steam within the same, and reduces it at once to a liquid condition, leaving a vacuum approaching more or less nearly to an absolute vacuum, according to the management of the apparatus. Fig. 88 represents a ver-

Fig. 88.



tical section of one form of condenser. It is a species of swelled pipe; the upper and lower extremities or necks are bored out so as to be of greater diameter at their inner than at their outer ends. Into these necks are inserted the extremities of pipes of corresponding form, as shown, the surrounding interstices being

filled up to make good the joints. The upper pipe brings the exhaust steam from the cylinder, and the lower one communicates with the air-pump.

Another form of condenser consists of a cast-iron cylinder fitted with a cover, and having the passage which serves to communicate with the air-pump cast on it. The condensers used in marine engines are not usually immersed in water, on account of the confined space in which they are employed.

Condensers of the second class are far more intricate and varied in their forms than are those which we have just described, the object in using these being to recover pure and unmixed the water resulting from the steam which has passed throughthe engine, which is very desirable when clean water cannot be obtained, or when the water contains much mineral matter, such as is the case with sea water. Attempts have been made from a very early period down to the present time to produce a surface condenser which should be efficient, the first consisting of two thin cylinders of large diameter, placed concentrically one within the other, water being allowed to circulate around the outer tube and within the inner one, the steam to be condensed being introduced into the annular space bounded by the peripheries of the two concentric cylinders. This contrivance was, however, found in practice to be unequal to the duties required of it; it was consequently abandoned, and condensers of the first class were for a time exclusively employed. Subsequently a form of surface condenser was introduced, which has proved more successful. It consisted of a number of tubes of small diameter, around which water was permitted to flow, and into these tubes the exhaust steam was passed and there condensed, and from the condenser the water thus formed may be pumped directly back to the boiler. This apparatus is that invented by Samuel Hall. Since the production of this form of surface condenser, a great variety have been introduced to public notice, and it has also been attempted, in some instances with success, to use air as the cooling medium in the place of water, in order that the principles of condensation might be applied where sufficient water for the ordinary condensing apparatus could not be obtained. Craddock's condenser, intended for use with either air or water, consists of a number of small tubes attached at the top and bottom to vessels which serve to afford communication amongst all tubes.

This condenser, being caused to revolve rapidly in air or water, is found tolerably efficient, as with the former medium a vacuum equal to nine pounds pressure per square inch may readily be obtained. Surface condensers, to be used with air, have also been formed of thin plates fixed parallel to each other, between which is passed the steam to be condensed. When air condensers are attached to locomotive carriages they may be fixed, as the velocity of the carriage itself is sufficient to cause the required circulation of the air. With regard to the construction of the various forms of condensers, it is only necessary here to observe that those of the first class merely require to be turned, planed, or faced at the joints, and those of the second class are somewhat similar in their construction to multitubular boilers. An account will be hereafter given.

The next element to which our attention is directed is the air-pump, by means of which the condensed steam, the water used for condensing it, and the air which is always contained in the latter, is withdrawn from the condenser, together with any portion of steam which may escape condensation, so that the vacuum produced previous to starting the engine may remain unimpaired while it continues in action.

The air-pump consists of a cylinder accurately bored, within which the piston moves air-tight. There is a valve at the foot of the air-pump, opening in such a manner as to allow of the passage from the condenser to the air-pump of such matters as are to be withdrawn from the former; whilst another valve at the top of the pump allows of the exit, and prevents the return of the same from and to the pump. The water, &c. below the piston is allowed to pass through it by means of valves opening upwards, the action of the apparatus being as under. As the piston, or bucket as it is called, of the air-pump rises, the water, air, and vapour in the lower part of the condenser pass through the bottom valve into the lower part of the air-pump; on the descent of the air-pump bucket, the water, &c. beneath it forces the valves formed in it open, and passes through to the upper side, and when the bucket again ascends, the water upon it is raised and forced through the upper valve into the hot well. This constitutes what is termed a single-acting air-pump. When the pumps are made double-acting the bucket is replaced by a solid piston, and two sets of valves are employed, so that when

the piston ascends, it draws in water below, and forces other water out above, and on its descent it draws above and forces below, so that the pump works during both the up and down-stroke; whereas, in the former case the pump is only effective during the up-stroke. The material of which the cylinder of the air-pump is formed is frequently cast-iron, but it should be lined with brass or Muntz metal; and this is especially necessary when sea water or foul water of any description is used; the same material should also be applied for air-pump rods. Iron rods, covered with brass, are very frequently used, but they are found to waste away where they are joined to the bucket. The method of constructing air-pumps is as follows. The cylinder, if of solid brass, is simply bored out in precisely the same way as a steam cylinder; but when it is lined it is first bored out, and the lining then bent, introduced into it, and made to fit firmly by hammering it on the inside, whereby the lining is expanded, so that the casing takes a firm grip; the lining is then bored out to the required size. The piston or bucket is accurately turned to fit the cylinder of the pump, and packed generally with hemp, which is tightened up by means of a junk-ring. Metallic packing has occasionally been used, but the vacuum obtained is not nearly so good, and, on the whole, it is inferior to hemp. The valves, if of metal, are accurately planed or turned, and then faced up or ground; various descriptions are used, but we shall not pause here to describe them, as a complete account will be given in a subsequent chapter.

With regard to the feed pump, it is only necessary here to observe that what are called plunger pumps are most generally employed; for a description of which the reader is referred to the chapter on pumps.

In concluding the present chapter, we may observe that it is the practice of some manufacturers to grind the steam cylinders and the piston-rods and similar parts; it is advisable to draw-file throughout their length, and polish.

In this chapter we have endeavoured to explain the form and mode of manufacture of the principal elements of the various kinds of steam-engines, omitting, however, various minor arrangements which require no special comment, and the action of which will be illustrated by examples.

CHAPTER XIV.

ON PUMPS AND VALVES.

It is proposed in the present chapter to give a general account of those pumps which are most commonly employed in practice to raise water, avoiding anything further than a mere reference to such forms as are of doubtful efficiency. The first class which we shall consider is that which includes bucket or piston pumps, which are those most commonly used for the ordinary purposes of life; the principle of their action is as follows.

Let us suppose that we have a cylinder fitted with a piston, in which there is a valve capable of opening upwards, so as to allow of the ascent of a fluid through the piston, but effectually preventing its return. Let the bottom of the cylinder be closed, and also furnished with a valve opening upwards, at the termination of a short pipe, of which the lower extremity is immersed in water; let the piston fit the cylinder water-tight, and let it be at the bottom of its stroke. If the piston be now raised, there will evidently be a vacuum beneath it, into which the water will be forced up the short pipe, by reason of the external pressure of the atmosphere. The piston having arrived at the top of its stroke, is stopped, when the valve at the bottom of the cylinder will close by reason of its own weight; and if the piston be now caused to descend, the water beneath it will raise the valve in the same, and pass through to the upper side, and when another upstroke is made, this valve having closed, the water above the piston will be raised, and will flow over the top of the cylinder, the lower part of which will again be filled. The upper end of the cylinder or pump-barrel may be closed, and supplied with a valve to allow of the exit of the water raised, and to prevent its return upon the piston.

There is, of course, a limit to the height of the pipe which effects the communication between the bottom of the pump-barrel and the water to be raised, as it is evident that the pressure of the column of water under the pump-barrel cannot exceed that of the atmosphere. The height of a column of water which balances the atmospheric pressure is nearly 34 feet, hence the suction-pipe of an ordinary pump should not, in vertical height, exceed 30 feet. This form of pump, when fitted with an exit valve at the top, is sometimes called a lifting pump.

Piston pumps are also made with solid pistons, that is to say, having pistons solid throughout, not furnished with a valve. The water, in this case, is drawn into the lower part of the pump-barrel, through a valve opening inwards, and expelled through another valve opening outwards; this apparatus is called a forcing pump. The upper extremity of the cylinder may also be furnished with inlet and outlet valves, that water may be drawn and forced above as well as below the piston, in which case the pump-rod through which motion is imparted to the same, passes through a stuffing-box in the pump cover; during the up-stroke, this pump is drawing beneath and forcing above the piston, and during the down-stroke, the contrary takes place; this is called a double-acting force-pump. The packings of these pumps are usually cupped leathers, or leather collars, which may be easily made by pressing the leather into form under the influence of moisture and heat, after which they may be turned by means of suitable tools.

Piston pumps are sometimes furnished with a trunk, being then called trunk pumps. The trunk is, in fact, a hollow piston-rod, of cylindrical or oval section, the object of which is to admit of the use of a long connecting-rod which passes down the trunk, being jointed to the piston at the bottom of the same. The various forms of valves used for the buckets, and to regulate the entrance and the exit of the water, will be subsequently considered.

We will next turn our attention to the form and principle of action of that class of apparatus which comprises the various descriptions of plunger pumps. A plunger pump consists of a barrel or cylinder, slightly contracted at its upper extremity, and entirely closed at its lower end; within this cylinder another

solid cylinder or plunger works; its diameter being a little less than that of the pump-barrel, so that it may not come in contact with the sides of the latter. The plunger thus formed works water-tight through a stuffing-box packed with leather or hemp, and placed at the upper or contracted extremity of the pump-barrel, which is itself furnished with two valves, one of which opens inwards, the other opening outwards. The action of this apparatus is as follows. When the plunger makes an up-stroke, it tends to leave a vacuum equal to its own bulk in the pump-barrel; this space is, however, immediately filled by water entering through the inlet valve; on the descent of the plunger the same quantity of water is expelled through the outlet valve; this pump also acting as a forcing pump, and is used generally for feeding steam-boilers and for working hydraulic presses, and is very frequently applied to large pumping engines. When the plungers are of very great size, they are frequently made hollow, in order to save weight; but it sometimes occurs that it is necessary for them to be heavy, as in the pumps of the Cornish engines, where the plunger is raised by steam-power and descends by the gravity of its own weight alone, or aided by extra weights placed upon the plunger pole. Plunger pumps are also sometimes made as trunk pumps, in which case the plungers themselves, being hollow, constitute trunks.

The plungers of these pumps having been accurately turned, should be draw-filed through their whole length, the packings, if of leather, being lubricated with water, and if of hemp, with oil. The efficiency of pumps of the two classes described above, depends principally upon the valves, and if these can be made perfect in their action, then will a barrelfull of water be raised at each stroke of the pump. The effective work done by the pump is found from the expression

$$w = 10 \times q \times h$$

in which w represents the work done during one stroke, expressed in foot pounds; q the quantity of water raised during one stroke, expressed in gallons; and h the height in feet from the level of the water in the well to the point of discharge, that is to say, the height to which the water is raised.

Centrifugal pumps are now occasionally used for raising water

when the lift is not very great; they act by imparting centrifugal force to a mass of water in a cylindrical box or casing. The moving part of the pump consists usually of a shaft, upon which are placed arms carrying vanes, the whole forming a species of fan. When this is caused to revolve rapidly, rotatory motion is imparted to the water in the casing which surrounds it, which causes the latter to press against the periphery of the casing, and to pass out at an aperture in the same, whereby a partial vacuum occurs about the axis of the fan, into which water flows through a suction-pipe. The advantage of this pump is, that it is capable of passing impediments which would choke the valves of an ordinary pump, but its efficiency is less.

Many years since, an apparatus called a spray pump was proposed, constructed on principles derived from the following considerations. It was found that if water be allowed to fall freely through air in a fine shower, the velocity with which the drops fall does not exceed about twelve feet per second; hence it was concluded that an upward current of air, moving with a velocity of, say twenty feet per second, passed through a stratum of water, will carry with it an upward shower to any required height. This apparatus was, however, found to be practically far from economical, which may be attributable, in a great measure, partly to the fact that a high-pressure engine was used to propel the fan which created the current of air, and partly to the inefficiency of the fan itself.

We have mentioned this last contrivance on account of the ingenuity of the principle on which it is based; but it is quite unnecessary to give any account of the designs innumerable which have been brought forward for raising water, and which have never been carried successfully into practice.

It now remains to describe the various forms of valves most commonly used for pumps. The clack valve is probably the oldest, and is very simple. It consists of a flap of leather, or other suitable material, covering an orifice and fixed down at one edge, so as to open as it were on a hinge; the leather flap requires to be covered top and bottom on the central part with plates of metal, in order to add to its weight, so that it may close rapidly and impart to it sufficient rigidity. These valves are frequently made of india-rubber closing upon a grating, instead

of over one large opening, and a method has recently been brought forward, whereby that part of the valve which is bolted down to form a hinge is made of hard india-rubber, thereby obviating the necessity of using strips of iron to form a hold for the bolts which formerly existed. Guards are fixed over the valves to prevent them from rising too high. When one piece of leather or other substance used for the valve is fastened down in the centre, so as to form two clacks, the arrangement is termed the butterfly clack. The principal disadvantages attendant upon the adoption of this form of valve in large pumps, are, firstly, the loss of water caused by the slowness with which the valve closes, the column of water above it beginning to return before the valve reaches its seat; and secondly, the great concussions produced by the fall of the valve with the column of water upon it, the loss of water during the closing of the valve sometimes amounting to one-eighth of the whole quantity raised.

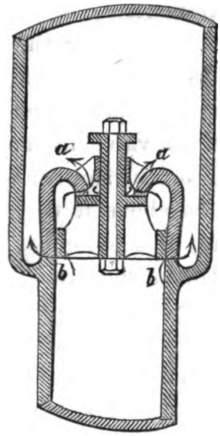
The next form of valve to which we shall refer is the conical valve, which consists of a flat or slightly curved plate of metal, of which the periphery is in the form of a frustrum of a cone, fitting into a seat of corresponding form. In order that this valve may rise vertically, it is sometimes furnished with a spindle, moving in guides, and sometimes furnished with a tail or stalk in the form of a triple feather, proceeding from its lower surface, and fitting the pipe beneath the valve; stops are placed above the valves to limit their rise.

Another form of valve consists of a short india-rubber tube, flattened at the extremity. When water is forced into the open end of such tube, it passes through, forcing open the flattened extremity; but in the contrary direction, pressure closes the tube more effectually.

It is a great desideratum to obtain a valve which shall close rapidly, so that it may reach its seat before the column of water above it begins to return, whereby loss of water is obviated and concussions avoided. In order to obtain effects so desirable various forms have been produced, of which the best is the double-beat valve of Messrs. Harvey and West, of which a vertical section is shown, Fig. 89. This valve has two seatings, *b b* and *c c*, and when the valve is raised by the pressure of the water beneath it, the latter flows out in the directions indicated

by the arrows. *a a* is a collar which prevents the valve from rising too high; washers of leather are placed beneath this collar to obviate the blow of the valve in rising.

FIG. 89.



Another form of valve, by Jenkyns, consists of a disc valve, itself perforated, so as to form the seat for another disc valve; the number thus superposed depending upon the diameter of the orifice which the valve is designed to close. Another description of valve which has been proposed consists of numerous concentric annular orifices closed by rings, and this has recently been improved upon by making the rings of india-rubber, as done in Mr. Hosking's valve.

A valve commonly used for locomotive feed pumps, consists of an accurately formed sphere of metal, falling into a spherical seat, its rise being regulated by guards.

The surfaces of contact between valves and their seats must be got up by scraping or grinding, so as to exhibit the highest degree of accuracy attainable; and when of metal they should both of them be of the same metal, as otherwise galvanic action is produced, causing the corrosion of that surface which is formed of the most electrically positive metal. Seatings formed of hard wood, placed with the grain endways and kept constantly wet, are found satisfactory in practice.

Before concluding our observations upon valves, a few remarks

on the height of rise which should be allowed, and upon the power required to work them, may not be inappropriate.

It is evident that for the whole effect of a valve to be obtained, its rise should be such that the waterway between the seating and the edge of the valve be not less than the area of the valve. For a semicircular clack valve, the extreme rise is found as follows. Let r = radius of valve, h = height of rise, the area of the valve will evidently be

$$= \frac{3 \cdot 1416\, r^2}{2}$$

and the waterway between the seating of the valve and the edge of the same will be

$$= \frac{3 \cdot 1416\, r\, h}{2}$$

hence the whole area could only be utilized when the valve opens to a vertical position, which is of course inadmissible; hence valves of large radius must be employed.

For disc valves, we have for the area of the valve,

$$3 \cdot 1416 r^2$$

and for the waterway between the valve and its seating

$$6 \cdot 2832\, r\, h$$

hence, the proper rise is found from the expression

$$h = \frac{r}{2}$$

This also applies to the ball clack.

In the double-beat valve, let r = the lesser, and r' the greater diameter, for the seatings; then the effective area of the valve is

$$= 3 \cdot 1416\, r'^2$$

and the area of waterway given by the rise of the valve is

$$= 6 \cdot 2832\, h\, (r + r')$$

hence

$$h = \frac{r'^2}{2(r + r')}$$

It may be observed that if

$$r = r'$$

the valve is not affected by any difference of pressure above and below it; it is then called an equilibrium valve, which is much used in Cornish pumping engines, and the nearer the value of r approaches to r', the greater will be the pressure required per square inch to open the valve.

CHAPTER XV.

ON BOILERS.

In a previous chapter we have set forth the principles upon which steam boilers generally are constructed, and in the present we propose to render an account of those generally used; for which purpose we have carefully selected such examples as appeared best suited to give a general idea of the objects aimed at in the construction of steam boilers and of the means employed to attain such objects.

Perhaps the simplest form of boiler now largely employed to generate the steam requisite to actuate steam engines, is that known as the Cornish boiler. It consists of an external cylindrical shell, through which passes a tube which serves to carry the flame and heated air from the furnace. The extremities of the boiler being closed by flat plates, the water is contained in the space included between the inner and outer cylinders.

The thickness requisite to each part of the boiler may be determined from the following formulæ with quite sufficient accuracy for all practical purposes, the boiler being made of wrought-iron.

Let r = radius of outer shell, r' = radius of inner shell or flue, $t\ t'$ thicknesses of outer and inner shells, t'' thickness of end plates, all in inches, l = length of flue in feet, p = greatest pressure in lbs. per square inch to which the boiler will be subjected.

Then

$$t = \frac{p.\ r.}{7500}$$

$$t' = \sqrt{\frac{p.\ l.\ r'}{60{,}000}}$$

and

$$t'' = 0{\cdot}0035 \left\{ r - r' \right\} \sqrt{p}$$

Formulæ for determining the evaporative values of boilers have been given already in Chapter X.

In order to exemplify the above-mentioned form of steam-boiler we have shown a longitudinal section of such an one on Plate XIII. The boiler there represented has been erected by Mr. Wicksteed to supply the new pumping engine at the Scarborough Waterworks, at Cayton Bay. The boiler consists of an external shell and an internal flue, and is furnished with the usual appendages, safety valves, pressure gauges, &c. It has been the custom to attach to such boilers a pipe to carry off the steam escaping from the safety valve, but it is evident that under proper management no such escape should occur, hence that detail is not added to the boiler illustrated.

These boilers are manufactured by riveting together a sufficient number of wrought-iron plates of suitable size, and the work should be so arranged as to break joint; that is to say, the longitudinal joint in one pair of plates should occur in a line with the centre of a plate in the next ring of plates, so that a horizontal section through the shell of the boiler at this place may exhibit half joint and half solid plate, and it is upon this supposition that the above formula for the outer shell has been calculated; for if the joint runs longitudinally from end to end of the boiler it will become

$$t = \frac{p.\ r.}{5000}$$

and if the metal were solid throughout

$$t = \frac{p.\ r.}{10{,}000}$$

From this formula it is evident that the thickness of a vessel subject to internal pressure, of circular section and with thin sides, should vary directly as the radius and as the pressure; hence if radius and pressure both increase, the corresponding thickness will increase very rapidly; hence it becomes desirable that when very high pressures are requisite the radius should be as small as

possible, to avoid the use of metal of thickness greater than is absolutely necessary to satisfy the conditions of safety.

In accordance with these views, various designs have been originated in order to obtain boilers which should possess at once the qualifications of strength and lightness, and one of the best adapted to these requirements is illustrated in vertical horizontal section at Plate XIV., having been invented and patented by Mr. Craddock, and capable of working safely under a pressure of from two to three hundred pounds per square inch.

This boiler will be observed to consist of numerous water tubes placed side by side in close contact around a fire, and forming as it were the sides of the furnace, and, by the form thus produced, offering a very large surface to the action of the flame in comparison to the contents of the tubes, and the smaller the tubes become the greater is this effect. The area exposed to the action of the heat is found from the following formula:

Let d = diameter of furnace in feet, h = total height of tubes above fire-grate in feet, a = absorbing surface in square feet,

$$a = 5\ d.h.\ \text{nearly.}$$

Taken vertical surface as equal to half the horizontal surface, the nominal horse-power becomes

$$= \frac{2{\cdot}5\ d\ h}{8{\cdot}1}$$

$$= 0{\cdot}308.\ d.\ h.\ \text{nearly.}$$

These water tubes terminate top and bottom in stout wrought-iron vessels called hearts, and the upper heart is surmounted by a steam dome, placed in the uptake of the chimney, whereby the steam is partly dried; to this dome the gauges, valves, &c., are attached. The water tubes are deviated from their vertical positions at top and bottom to allow the entrance of air to effect combustion and the exit of flame and heated gases; and they are also deviated in front of the grate to admit of the insertion of a fire door. The course of the current of air and gases is as follows. The atmospheric air required to effect the combustion of the coal enters under the grate through an orifice left beneath the furnace door, whence it passes through the incandescent fuel and upwards to the bottom of the upper heart, whence it escapes

through the openings between the upper extremity of the tubes; thence it passes down between the outside of the tubes and the masonry, and finally escapes into the uptake. The horse-power equivalent to the inner absorbing surface has been given above, and a similar formula will give that which is due to the external absorbing surface. This boiler was found to work very economically, but by reason of the small quantity of water which it contains requires some rather delicate contrivance to regulate the draft, which is supplied by a self-acting damper opened by an air spring, which consists of a quantity of air imprisoned in the closed end of a cylinder, and acted upon by a piston fitting such cylinder air-tight and carrying a piston-rod connected with the self-acting damper. The inventor found the air spring preferable to any arrangement of metal springs.

Let us now see what must be the thickness of the tubes of which the boiler is composed, supposing them to be of good wrought-iron, solid throughout, three inches in diameter, and intended to work under a pressure of 250 lbs. per square inch.

By the formula for cylinders we have

$$t = \frac{p.\ r.}{10000}$$

$$= \frac{250 \times 1{\cdot}5}{10000}$$

$$= 0{\cdot}0375 \text{ metes}$$

for the best Low-Moor iron. Hence we see that this boiler, if made with tubes of which the metal was one-twelfth of an inch thick, would be safer from the danger of explosion than an ordinary boiler working at a low pressure—of course, supposing that the hearts be made of ample strength.

The evaporative efficiency of this boiler will of course be improved by the thinness of the metal through which the heat is transmitted from the furnace to the water to be evaporated.

Various kinds of boilers have been proposed and constructed with a view to obtaining the advantages belonging to that which we have just described; but it does not appear that it has yet been surpassed for economy, although its introduction is perhaps retarded by the prejudice existing against the employment of very high pressures in steam machinery.

We will next proceed to describe types of the most common forms of marine boilers, and for this purpose will select two examples: one, Plate XV., being illustrative of an ordinary flue boiler; and the other, Plate XVI., exhibiting the construction of a marine flue boiler, both being longitudinal sections.

The flue boiler consists of a box-shaped boiler with flat or slightly curved sides, within which is the furnace, having at its posterior extremity a fire bridge, beyond which the flue passes on nearly to the end of the boiler, when it rises and returns along the upper part of the boiler, entering the uptake of the chimney near the front of the same. The steam is partially dried by resting in contact with the casing of the uptake.

The sides of this kind of boiler being flat, necessarily require to be strongly braced by numerous ties, pitched from 14 to 18 inches apart, according to circumstances. The pressure at which such boilers are worked seldom exceeds about 33 lbs. per square inch, and is more generally about 20 lbs. per square inch.

The tubular marine boiler is shown in longitudinal section on Plate XVI. It is similar to the flue boiler in general form; but the large flue is replaced by numerous small tubes, whereby a larger amount of heating surface is obtained. The air required for combustion enters the ash-pit, passes through the fire into the chamber at the posterior end of the furnace, whence it finds its way to the uptake through the numerous small tubes described above.

Locomotive boilers consist usually of two parts, presenting in longitudinal section the aspect shown Plate XXV. The one part contains the furnace or fire-box, which is surrounded on all sides save the bottom by water; ties are used to strengthen the flat sides of the fire-box, and the crown of the same is furnished with ribs.

In designing boilers of any description, care should be taken so to form the various parts that there may be no impediment to the escape of the steam to the upper part of the boiler as rapidly as it is generated; and for this purpose the joints should be arranged so that the recesses formed may not detain the bubbles of steam as they rise; also the sides of flues should not be made vertical, but inclined, so that the water spaces may be somewhat wider at the top than at the bottom.

The manufacture of boilers is very simple. Where it is required to rivet various plates together, they are usually first punched, then placed in juxtaposition and the holes trued by broaching or rhyming them out.

The rivets are made of bar-iron, being formed with one head: these rivets, when required for use, are raised to a cherry-red or white heat, inserted into their places, and there retained by holding a hammer against the head while the straight end is first hammered up into the form of a head, and then finished off in a conical or hemispherical form by means of swages which are called snaps. The riveting may be done either by hand or by machinery.

The stays are sometimes secured by screwing the ends and fitting nuts upon them; sometimes by riveting and sometimes by screwing and riveting. Riveting may occasionally be employed for securing metal when cold.

The tubes of multitubular boilers may be fixed either by riveting the ends over the tube plates, or by driving in ferules to spread the ends, the apertures in the tube plates being slightly conical; and, lastly, the tubes may be screwed.

Whenever plates intended to be riveted can at all conveniently be drilled, this method of perforation should be adopted, as by punching the metal is strained and the apertures thus produced are not cylindrical; also it is desirable that the plates shall not, when partly riveted together, be forced to fit by driving drifts through the opposite holes, as thereby a strain is thrown upon the shell to which it should not be subjected.

Land boilers are usually set in masonry, and marine boilers in cement.

We have omitted to mention hitherto the appendages which are common to all boilers. These are safety valves, loaded according to the pressure under which the boiler is intended to work; the valve may be acted upon directly by a weight or through the medium of levers, as shown in the illustration, Plate XIII.; or they may be kept down by springs acting through levers, and this is the method commonly used in locomotives.

Steam-pressure gauges are also requisite; they were formerly made of a syphon-formed tube containing mercury, the difference of the heights of the mercury in the two legs of the

syphon indicating the pressure of the steam. The most portable and convenient steam gauge now manufactured is that of M. Bourdon, which consists of a curved tube into which the steam has free access, and the steam by its pressure tends to straighten the tube, this tendency being opposed by the elasticity of the tube. By means of suitable connexions the motion of the tube is communicated to an index placed upon a dial, graduated to show pounds pressure per square inch. These gauges are also made to show vacuums. Gifford's injector is now frequently appended to steam boilers, to act in place of a feed pump. In this apparatus a jet of steam passes from the boiler through a mouth-piece, and is partly condensed, when it forces its way through another mouth-piece into the boiler again, carrying with it a quantity of feed water. Its action may appear paradoxical, but is in reality very simple, being as follows.

Suppose the area of the orifice from the boiler to be one square inch, then the steam passing from this aperture with any given velocity, it may be partially condensed without losing this velocity, so that the same amount of energy will be concentrated upon a smaller area; hence, when so partially condensed, it can readily re-enter the boiler and carry other water with it. This apparatus will not act if the temperature of the water be much above 110° Fah.

In addition to the above appendages, man-holes, mud-holes, furnished with doors, and blow-through cocks, are requisite, to allow of the cleansing of the boilers; also gauge glasses to show the level of the water in the boilers.

CHAPTER XVI.

ON PROPELLERS.

The three purposes which propellers are intended to fulfil are, the propulsion of ocean steamers, river steamers, and canal steamers, the latter consisting of tugs only; and the conditions to be satisfied are somewhat different for each class. Ocean steamers, besides requiring efficient power for the arduous work occasionally before them, demand that the machinery should be so placed as to be as safe as possible from enemies' shot; river steamers require to be compact; canal boats must be of light draught, compact, and must have their propelling apparatus of such form as may not cause injury to the banks. For these purposes only two propellers have hitherto been brought into general use, namely, the paddle-wheel and the screw; and to these, and one form of the hydraulic propeller, we purpose now to devote a few brief remarks.

The paddle-wheel, being the longest established, first demands attention. It is manufactured in two forms: paddles with radial float-boards, and feathering paddles. In the first the float-boards are firmly fixed upon radial arms; and in the second they are formed so as to be moveable upon an axis, their positions with regard to the horizon being regulated by means of rods, of which the outer extremities are attached, by pins, to arms upon the axes or gudgeons which carry the float-boards, their inner ends being similarly connected with the periphery of a ring fixed somewhat eccentrically to the paddle-shaft. The action of the floats of a paddle-wheel is as follows. Let us direct our attention to one float-board, the engine being at rest and the vessel in still water. Then if the engine be started, a pressure will be exerted upon the water behind the float, which will pass through

the water, a certain amount of motion being at the same time communicated to the vessel itself—the velocity attained being proportional to the pressure existing between the float-board and the water. Now it is evident that while the float-board is at rest, no pressure is exerted upon the water; but when it begins to move, resistance becomes manifest, such resistance increasing as the square of its velocity; hence if there be any motion of the vessel, there must also be some yielding of the water in a direction opposite to that of the vessel, and if the yielding or part of the yielding of the water takes place in any other direction, there is a loss of power. With the common radial paddle-wheel the water yields in a variety of directions, corresponding with the positions of the various floats at any moment. And besides this, a portion of the water between the float-boards necessarily acquires some centrifugal force, which throws it out from the wheel radially, and thus some energy is wasted in useless work. With the feathering paddles the action is somewhat different from the above; but there exists to some extent the same disadvantages.

The screw-propeller has for some time enjoyed a reputation superior to that of the paddle-wheel, notwithstanding that its use is accompanied by serious disadvantages. In the first place the situation of the screw tends to remove from the stern of the vessel the back water, thereby leaving a deficiency of pressure at the stem of the vessel, which is equivalent to increased resistance at the bows; again, considerable centrifugal force is imparted through the water in contact with the screw, which is accordingly dispersed radially; a corresponding amount of energy being wasted, and at the same time the concussion of such water as passes upwards against the dead wood of the vessel produces vibration. The resistances which a screw has to overcome in a heavy sea are probably on the whole much more uniform than those which are opposed to the motion of paddles, whereby the alternate racing and stopping of the engines are much reduced, but nevertheless, this injurious action exists in a very considerable degree.

The hydraulic propeller has been brought forward at various times in a variety of forms, but hitherto it appears to have failed as a practical propeller. We may instance Ruthven's propeller,

also the hirudine propeller. Ruthven's propeller consisted of a fan or rotatory pump, which expelled water through the extremities of channels towards the stern of the vessel. The motion of the vessel was due to the reaction of the issuing jets of water; the orifices from which these jets proceeded were placed above the water line, hence the resistance offered to the exit of the water was that due to the pressure of the atmosphere; it is therefore not difficult to imagine that this propeller proved useless as an economical means of obtaining motion. If the orifices mentioned above be closed, the pump may, nevertheless, be worked, and it will in such case impart only a whirling motion to the contained water; whence it appears that this propeller admits of the engine being driven without producing any useful effect.

The hirudine propeller consisted of a tube in which was a diaphragm, so formed that by means of vertical rods a wave was produced in it passing backwards, thereby carrying the water from the bows of the vessel and expelling it at the stern, so as to impart to the vessel a forward motion by the reaction of the water thus ejected; the action of course being intermittent, the water passing through the tube in waves. This apparatus appears to present fairer prospects of success than that last described, but it is many ways complicated and inconvenient. The name was given on account of some supposed resemblance to the action of a leech, though the true principle of the propeller can scarcely be regarded as analogous to the principle of propulsion exhibited by the leech.

The two propellers above described possess the great advantage of acting only in that direction in which the greatest effect is produced, namely, in a direction parallel to the vessel's course; whereas the paddle-wheel only acts in this direction in one position, and then also imparts centrifugal force to the atoms of water with which the float-board is in contact, and this force is also produced by the screw-propeller.

Neither Ruthven's nor the hirudine propeller has come into use, but of the two we think the latter the best, as the resistance of the water is employed instead of that of the atmosphere, while the parallel action of the propeller is retained.

More recently this same principle has been adopted in an inge-

nious apparatus designed by Mr. C. G. Gumpel, and patented by him a short time since. Plate XVII. shows various views of the apparatus alluded to. Beneath, or flush with the level of the bottom of the vessel, is placed a rectangular channel, running fore and aft, and expanded at the centre into a large chamber, above which are placed two cylinders, fitted with water-tight pistons. If we suppose one of these pistons to ascend, water will evidently enter the channel and fill up the cylinder beneath it, following the piston as it rises, and its descent will of course be accompanied with the expulsion of the water beneath it; and the action of the apparatus is such, that when one piston is ascending the other is descending, a regulating valve being introduced in the large chamber mentioned above, which so acts that the water passing through the propeller enters at the fore end of the channel, and passes out at the after end; the orifices through which it passes being capable of a variation of area to suit the velocities at which it may be desired to propel the vessel. In the Plate, Fig. 1 represents a longitudinal section, and Fig. 2 a plan of the apparatus. A B is the channel, C D are the pistons, E E the regulating valve, shown in position suitable when C is ascending and D descending; on the contrary, *k b* shows the position of the valve.

It would be premature to advance any decided opinion on the practical utility of this invention, but the author can testify to the satisfactory results of numerous experiments tried with a small model at various times and under a variety of adverse circumstances.

CHAPTER XVII.

ON VARIOUS APPLICATIONS OF STEAM POWER, AND APPARATUS CONNECTED THEREWITH.

In the foregoing chapters we have treated especially of those forms of machinery and processes which are of common application, in which, however, numerous applications of steam power and appendages to prime movers have of necessity been passed over; wherefore, the following pages will be devoted to the consideration of some of the subjects previously omitted.

We will commence with stationary engines. Of these the pumping engines appear to be the first found of practical utility, and even at the present day the Cornish pumping engine of 1835 is scarcely surpassed in point of economy; but the improvements suggested by Mr. Wicksteed in adapting the pump work to water-works purposes, and other improvements of less importance, have produced a greater economy, as is clearly shown in the comparison of long working of the two engines at the East London Waterworks as compared with the two best engines in Cornwall. (See "Further Elucidations," &c. Weale, 1859.)

It may be interesting here to pause for a moment to compare the economy of engines built twenty years ago with those of the present day; but we are at once confronted with a difficulty not easily surmounted, namely, the want of *reliable* experiments. Experiments, it is true, are recorded in sufficient number, but the reliability of many of these is indeed very questionable, for they are usually continued for about twenty-four hours or less, and the results of this short working, if considered favourable, are then reported. The inutility of such trials is sufficiently evidenced by the table on page 5 of Mr. Wicksteed's "Experimental

Enquiry," published in 1841, which shows the results of short trials upon the same engine with coals taken from the same heap; the minimum duty produced by 94 lbs. of coals was 63,650,298 ft.-lbs., and the maximum duty reached 118,522,475 ft.-lbs., or nearly twice the minimum duty.*

The existence of such facts as these will naturally make those interested in the economy of steam power careful to know the circumstances under which engines are experimented upon, to avoid the disappointment of finding the working economy of steam power far inferior to that deduced from experiments. The only cases which can be quite satisfactory to the practical man are those where *all* the particulars of the trials are published; such, for instance, as quantity of water evaporated, duration of trial, state of fires, &c., &c.; the duty given *alone*, without any account of the evaporative value of the fuel used, being almost useless. Suppose, for instance, the consumption of fuel only in the "Thetis" and "Inca" during the experiments published some time since, be taken into consideration, it will give a vast superiority to the former, whereas, when allowance is made for the different evaporative values of the fuel employed, the difference of economy in the two vessels is small. The only trials with which we are acquainted which supply all that can be desired, are those published in the "Experimental Enquiry" alluded to above, and we are further strengthened in the opinion that no others are extant from the remarks in Bourne's "Treatise on the Steam Engine," new edition, page 110, which are as follows. Having reference to the comparison of theory with experiment Mr. Bourne says:—"In order to test the practical value of this theory, it will be useful to compare its results with those of the experi-

* This opinion is completely corroborated by the following statement of the duty done by the Fowey Consols engine at the well-known trial in 1835, which was so far superior to that during the working of the same engine for long periods. (*See* "Further Elucidations," p. 14.)

At the twenty-four hours' trial . . .	134,100,000	ft.-lbs.	per cwt.
Highest duty in any one month during eleven years	99,422,891	"	"
Average duty for the year 1835 . . .	86,446,269	"	"
The month before the trial	93,034,325	"	"
The month of the trial	94,912,548	"	"
The month after the trial	97,559,843	"	"

ments which were made by Mr. Wicksteed on the large Cornish pumping-engine, built under the direction of that eminent engineer by Messrs. Harvey and West, for the East London Waterworks, at Old Ford, and which were published in 1841. The dimensions and structure of the engine and the details of the experiments are stated with such minuteness and precision that there is none of that uncertainty respecting the circumstances of particular cases which is the most frequent cause of failure in the attempt to apply theoretical principles to practice."

We have dilated somewhat upon this subject, as it is of vital importance to the progress of steam engineering to be acquainted with the actual success or otherwise of the various forms of steam-engines. In 1859 Mr. Wicksteed published an account of the duty of the "Wicksteed" engine at the East London Waterworks, obtained from *three* years' working, which of course can leave no doubt upon the mind as to reliability.

We will now compare, as far as our means will allow us to do so, the results of certain pumping engines.

From Mr. Wicksteed's experiments (1841) we find that a duty of 108,198,102 ft.-lbs. per cwt. of fuel was obtained on a long trial of the Cornish engine of the East London Waterworks; 122,376,128 ft.-lbs. at the trial of the Holmbush engine; 130,248,384 ft.-lbs. at the trial of the Fowey Consols engine. From the working of the "Wicksteed" engine for three years, a duty of 109,000,000 ft.-lbs. is obtained, for best Welsh coal. (See Mr. Wicksteed's pamphlet, "Further Elucidations," &c. 1859).

As a specimen of more recent construction, we may refer to an engine erected for the Chelsea Waterworks' Company, and reported upon by Mr. Joshua Field, April 9th, 1857. The trial, as reported, lasted for 24 *hours only*, and a duty of 103,900,000 ft.-lbs. per cwt. of coal was obtained.* This result shows not only an absence of improvement, but an inferiority to the above-mentioned engines, which might scarcely be expected when we view the general improvements effected during the last twenty years. The Cornish engine above referred to was constructed about 1835.

In the Cornish engine the motion of the plunger-pole is controlled only by the internal resistances, the plunger-pole of the

* Mr. Field's Report; Bourne's Treatise. Appendix.

pump being suspended from the end of the beam, and no fly-wheel being employed. Recently, fly-wheels have been applied to pumping-engines, but without producing satisfactory results.

Formerly, beam engines were universally employed to drive mill work, when large power was required; and in fact Newcomen's type appears to have formed the basis of all the earlier engines; beams being used for marine engines also. The advantages attendant upon more compact forms of machinery did not long remain unobserved, and recently beam engines have been almost entirely superseded by direct-action engines for marine purposes, where economy of space is a desideratum. A great many of the improvements effected in the construction of stationary or land engines have arisen not so much from the necessity of improvement in this one class, as from the restrictions under which the engineer acts when designing steam machinery for marine and locomotive purposes. The difficulties attendant upon the adaptation of steam power under the circumstances last re-erred to necessarily increase in proportion as the space at command diminishes; wherefore the engines of the small river steamers are generally more compact in form than the bulky machinery of the larger steamers.

Among the particulars not hitherto specially entered into we may mention various contrivances for facilitating the consumption of the smoke; the principle of them being in itself exceedingly simple, as all that is necessary in order to ensure the consumption of the smoke is, to mix a sufficient quantity of atmospheric air with the same, at a temperature not lower than that at which the gases burn. Notwithstanding the apparent simplicity of this operation, the means of carrying it into practice do not readily present themselves, as appears evident from the great number of methods which have been proposed to obviate the nuisance and waste given rise to by the evolution of smoke. Prideaux's furnaces appear, upon the whole, to be best calculated to effect the desired end with economy, but one of the chief requisites to smoke consumption consists in properly managing the fires.

Another source of economy which has lately been much used consists in superheating the steam; that is to say, imparting to it a temperature higher than that due to its pressure; thereby

avoiding, in some degree, condensation in the steam cylinder, The steam may be superheated by contact with hot flues passing through the steam space of the boiler, or the steam may be caused, in passing from the boiler to the engine, to traverse pipes placed in the uptake of the chimney shaft or passing through the furnace. The introduction of superheated steam has, in some cases, been found useful in the absence of the steam-jacket, which consists of an outer cylinder or jacket placed around the working cylinder of the engine, the small annular space left between the two being kept full of steam from the working boiler, or from a separate boiler. Sometimes the steam jacket is replaced by a hot-air jacket, and in every case, whether the cylinder be jacketed or not, it should always be well clothed, to avoid the radiation of heat from its surface into the surrounding air. Clothing should also be applied to the boiler and steam-pipes, and in some cases a very great amount is requisite; such, for instance, as that of the locomotives designed to traverse the ice in the frozen regions of Siberia. Under these circumstances, thick coatings of felt, covered with coatings of wood, may with advantage be employed, the cylinders being similarly protected. Loss of heat from the sides of flues of stationary boilers may be much reduced by leaving an air space around them, completely closed in by masonry, so that the air cannot circulate. It is frequently necessary to supply the stationary and other boilers with small feed pumps, which may be worked by hand or by donkey engines.

Large marine engines are also very commonly supplied with small steam-cylinders to work the starting gear.

The means of ascertaining the amount of duty obtained from rotating engines are very insufficient, the indicator and the friction brake being most commonly used. The indicator consists of a small brass cylinder, furnished with an accurately fitting piston, capable of moving steam-tight, but with very little friction; this piston, when unacted on by any other force, is retained at the lower end of the cylinder by a spiral spring above it. It carries a piston-rod, to which is attached a pencil-holder, which, when the instrument is required for use, is furnished with a pencil, the point of which rests upon paper, which is caused to move under it in a direction at right angles to the axis of the cylinder of the indicator, the motion being derived from some

part of the engine. If this indicator be attached by its lower extremity to the cylinder of the steam-engine, it is evident that when steam enters the working-cylinder, the indicating piston will rise, compressing the spring above it, the amount of compression being proportional to the pressure of the steam, and as the engine moves the card also moves under the pencil; thus a diagram is obtained, showing the pressure of steam in the cylinder at every part of the stroke of the engine, and from such a diagram, the mean pressure of steam in the cylinder during one stroke may readily be calculated. The horse-power calculated for this mean pressure is called the indicated horse-power.

The friction brake in its common form consists of a band containing wooden blocks, which is placed around the main shaft of the engine, and tightened up until the same is brought to its accustomed speed; then, from the extremity of an arm fixed to the band, weights are suspended until the arm remains horizontal. The amount of work done by the engine in any given time is calculated by multiplying the weight attached to the brake by the distance of their point of suspension from the centre of the main shaft, and by the number of evolutions of the same.

Steam carriages and traction engines for common roads have lately attracted much attention, and many ingenious forms have been designed and executed and frequently exhibited in the metropolis; and for some time past, Bray's traction engines have been much used. These engines are not intended so much for speed as to draw heavy loads at a small cost, hence gearing is employed to produce the speed of the engine; toothed wheels being sometimes employed, and sometimes chains. With the former some inconvenience is found, when running on rough roads, from the variation of distance between the toothed wheels, which of course interferes with their smooth action. In Messrs. Longstaff and Pullan's engine, the cylinder and its attachments are placed upon frames capable of moving upon an axis, so as to allow the driving wheel to rise and fall over the inequalities of the road without affecting the distance between the centres of the toothed wheels.

A very light form of steam carriage has been designed for common roads by Messrs. Yarrow and Hilditch, in which arrange-

ments are made to prevent the action of the springs to which the driving wheels are attached from interfering with the motion of the slide valve; but the absence of horn plates allows lateral strain of the piston-rod, &c., and until this is supplied the action of the machine cannot be relied upon.

We have now concluded the few remarks which appeared desirable to render the previous descriptions more complete. It would be utterly impossible, in ordinary limits, to notice one tithe of the various forms in which the steam-engine exhibits itself, but we have endeavoured to select examples as general as possible.

CHAPTER XVIII.

ON PUMPING ENGINES.

There is, perhaps, no method of imparting information practically more effective than that which is based upon the illustration of good examples, which show at a glance the manner in which scientific principles are rendered available for the daily purposes of mankind; and such a treatise as the present would certainly be very incomplete without some detailed account of the present practice.

We have selected, in order to exemplify the most useful forms of pumping engines, two erected by Mr. Wicksteed, through whose courtesy we are enabled to supply the plates and description of the same.

Plates XVIII. and XIX. illustrate the Grand Junction engine, erected at the Grand Junction Waterworks, at Kew. It is constructed on the same principle as the celebrated "Wicksteed" engine, subsequently erected at the East London Waterworks, and was executed by Messrs. Sandys, Carne, and Vivian, the contract being dated 1845.

Plate XVIII. shows a general elevation of this engine. *a* is the steam cylinder, which is surrounded by jacketing and clothing; *b* is the valve-casing and framing for valve gear, which gear is actuated by tappets on the plug-rod *c*; *d* is the piston-rod, the upper extremity of which is attached to a parallel motion, *e f*, *g h*, *j*, of which the centres *e f g* and *h* are moveable, the centre *j* being fixed; this parallel motion is joined at *g h* to the main or working beam, and to that extremity of the latter to which the parallel motion is attached, is fixed a catch beam *k*, to prevent the piston from descending too low. The main beam is supported at the centre of its length upon a gudgeon resting in

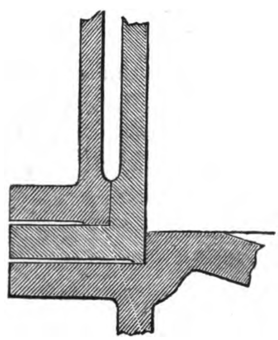
bearings carried by an entablature supported upon columns, as shown.

Passing from the main centre just described, we first come to a rod, by which the feed pump *l* is worked; the motion of this rod is rendered nearly rectilineal by connecting it with a parallel motion which extends to the end of the beam, and to which is attached the rod actuating the air-pump *m*. From the end of the beam the plunger-pole *o* is suspended, which works vertically in the barrel of the main pump, *p*; upon this plunger-pole is fixed a table, carrying weights, which are enclosed in the casing *w*; *n* is the hot-well placed above the air-pump *n*, and it is from this hot-well that water is drawn by the feed pump *l* to supply the boiler which furnishes the engine with steam. *r* is the eduction pipe leading from the cylinder to the condenser, which, together with the air-pump, is placed in the cold water well. In addition to the details shown in the elevation, there are two cataracts—one on either side of the valve gear. The general arrangement of the engine having been now explained, we will proceed to describe each part in greater detail.

The cylinder is bedded upon a mass of masonry, to which it is secured by six long holding-down bolts, furnished with nuts at their upper extremities and fixed at the lower by washers and gibs; these bolts are about two and a half inches in diameter, and descend through masonry to a depth of about fourteen feet. Upon the masonry rests the casing of the cylinder bottom, the total height of which is about two feet, and it is upon the lower flange of this cylinder casing that the hollow struts are placed to receive the upper extremities of the holding-down bolts; these struts are two feet eight inches high from the floor, and the thickness of the metal is one and a half inches at the lower part, reduced to one and a quarter at the upper. The casing for the cylinder bottom consists of a short cylinder cast in one piece of the cover, which is convex downwards, and it is closed by a loose bottom; the space between the top and bottom of this casing inside being at the centre about seven inches and a half, and at the circumference about eighteen inches. Upon this casing rests the cylinder, of which the internal diameter is about seven feet six inches; the thickness of metal being about one inch and three-quarters. Round the cylinder is the jacketing, between which

and the cylinder a steam space is left; and the flanges of the casing for the cylinder bottom, and the cylinder, and the jacket are all bolted together, forming a joint, shown Fig. 90, which is drawn to a scale of one inch to a foot. Outside the jacketing is an air space, surrounded by timber clothing: similar precautions to those described above for preventing loss of heat are

Fig. 90.



observed in the construction of the cylinder-cover, through which the piston-rod passes, steam tight, by means of an ordinary gland. The diameter of the piston-rod is about eight inches.

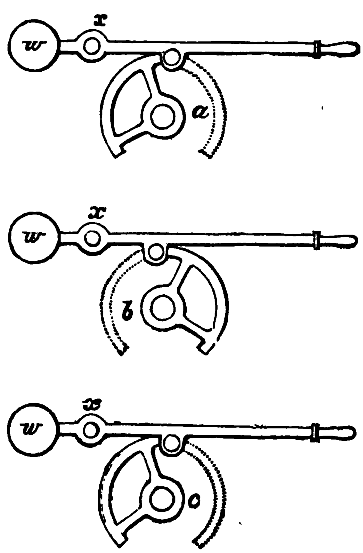
In order to render evident the arrangement of the valves and valve gear, we must refer to Plate XIX., in which two elevations of the gearing are shown. A glance at the front elevation of the valves shows that four are supplied: they are double-beat valves, having the top and bottom beats of equal diameter, three being placed at the upper end of the cylinder, and one at the lower. The three upper valves are, the starting valve, the steam valve (through which steam is admitted to the upper extremity of the cylinder), and the equilibrium valve (through which steam passes from the upper to the lower side of the piston). The lower valve is the exhaust, through which the steam passes from the lower side of the piston into the condenser. To each of the three upper valves is attached a stem passing through a stuffing box, and through a guide; this stem is acted upon by the short end of a lever, the position of which is indicated by the dotted lines. From the longer end of the lever a rod descends, of which the lower extremity is attached to an arm carried by one of the weigh shafts

of the valve gear; the arrangements being such that, when the valve rods and the arms to which they are attached are in the same straight line, the valves are closed. The exhaust valve is similarly actuated; but in this case the lever to which the valve rod is attached is bent. In connexion with the valve gear are three weigh shafts,—the upper one being connected with the steam valve, the centre one with the equilibrium valve, and the lowest with the exhaust valve. The three weigh shafts, which we shall designate the steam equilibrium and exhaust valve shafts, are marked *a*, *b*, and *c*, respectively in both views. To these shafts are keyed arms, *a d*, *b e*, and *c f*, from the extremities of which rods are suspended, connected at their lower ends with cast-iron balance levers, to which are hung weights. The tendency of these weights is to open all the valves. Another set of arms is also attached to the weigh shafts, by means of which the valves are closed: these arms or handles are shown in both views at *a g*, *b h*, and *c i*. It will be observed that the weight in connexion with the shaft *a* when descending, opens the steam valve and causes the arm *a g* to rise to the position shown in the dotted lines. The weight connected with the shaft *b* in descending, opens the equilibrium valve and throws the handle *b h* down to the position shown by the dotted lines, and the weight acting upon the bottom shaft opens the exhaust valve, and raises the handle *c i*; hence we see that the valves are opened by the descent of the weights. We must next observe the means of closing them. The plug-frame consists of two rods, *m m*, *m m*. These rods carry tappets, *k*, *l*, and *n*. Let us suppose that the engine is about to make a down stroke, then the arms *a g* and *c i* will be in their highest positions; as the plug-rods descend the tappets *k* will strike the arms *a g*, and depress them, thereby closing the steam valves and raising the balance levers connected with the shaft *a*, and subsequently the tappet *l* strikes the arm *c i*, closing the exhaust valve and raising the balance levers connected with the shaft *c*. These arms, thus depressed, are retained in the position into which they are thrown by means which will subsequently be described.

When the engine is about to make an up stroke, the arm *b h* is in its lowest position, the equilibrium valve being open. During the ascent of the plug-frame the tappet *n* raises the arm

b h, closing the equilibrium valve, and raising the balance lever connected with the shaft *b*, this position being retained by means of a catch. It is now necessary to explain the manner in which the catches act; and in this we shall be assisted by the woodcut, Fig. 91, in which *a*, *b*, and *c* are the three weigh shafts, to which are attached quadrants, as shown, being fixed at the ends of the shafts. When the handles are acted upon by the tappets, the shafts revolve so that the quadrants assume the positions shown in the woodcut, in which they are retained by the pins attached to levers, moving upon fulcra *x*, *x*, *x*, and equilibriated by weights

Fig. 91.



w, *w*, *w*. If the catches be raised the balance levers cause the quadrants to assume the positions indicated by the dotted lines, the pins in the catch levers then resting upon their peripheries. The extremities of these catch levers are shown (Plate XIX.) at *a′b′c′*. We have now shown how the valves are closed, and retained closed, but it yet remains to show how the catches are raised to allow the balance levers to open the valves. This is effected by cataracts, of which there are two, shown at *o o*, Plate XIX. These cataracts are species of pumps, fitted with a solid plunger packed with

leather. Their action is as follows. Upon the plug-rods *m m* are fixed tappets *p q*, which act upon levers *p r* and *q r*. During the down or indoor stroke, the tappet *q* depresses the end of the lever *q r*, winding the band *s* around the pulley *t*, and drawing down the end *u* of the rocking beam *u v*, and elevating, therefore, the end *v* of the beam; at the same time drawing down the rod *u u* and pushing up *v v*, thereby raising the plunger of the cataract, which as it rises draws water freely through a valve from the cistern below it; then the weight on the plunger-rod of the cataract, together with that suspended from the end *v* of the beam, causes the plunger to descend, forcing out the water from beneath it, through a stopcock, back into the cistern from whence it was taken—the velocity with which the plunger descends being regulated by the opening of the cock. In concluding its down stroke, the cataract, by means of the rod *u u*, releases the catches on the top and bottom weigh shafts, thereby allowing the balance levers to open the steam and exhaust valves, when the engine will make another down stroke. The cataract on the opposite side of the engine is raised during the up stroke, and releases the catch on the shaft *b*, to allow the equilibrium valve to open to cause the next up stroke. The amount of waterway allowed by the cataract cocks determines the time which elapses between two strokes, and thus the speed of the engine is regulated. The position of the tappets *k k*, which close the steam valve, admits of adjustment by means of the screw *y*, and upon their height with regard to the plug-rod depends the point of the stroke at which the steam will be cut off. Their length is necessary in order that they may hold the handles *a g* down until the cataract which governs the catches *a′ c′* has been raised so as to allow the catch *a′* to secure the steam valve. We have very minutely described the form and action of the valve gear of this engine on account of its complicated character, in order to leave no means unemployed by which it could be explained, as it is highly important clearly to understand this beautiful part of the mechanism of the engine, upon which its action is dependent.

The parallel motion is formed of bars, carrying brass bearings in the usual manner. The main beam consists of two beams braced together, its length from cylinder centre to the pump centre, is thirty-six feet eight inches, each of these centres being

eighteen feet four inches from the centre of the beam; the depth of the beam at the centre is about seven feet six, and at the extremities about two feet eight. The two beams are braced together by six ties, one and a quarter inches in diameter, of wrought-iron, passing through distance pieces eight inches in diameter; the two pieces of the beam are about three feet four inches asunder, the metal three inches thick, and the main gudgeon one foot four inches in diameter. The distance from the cylinder centre along the beam to the first parallel motion centre, is eight feet four inches, and to the plug rod centre, ten feet four inches—the latter being eight feet from the main centre of the beam; the feed pump centre is four feet seven inches from the main centre, and the air-pump centre ten feet—the latter being eight feet four inches from the main pump centre. The parallel motion for the main pump is similar to that for the piston rod; the diameter of the main pump rod is eight inches, that of the casing containing the weights is five feet eight inches outside, and five feet five inches, its height being eight feet four inches. Below the casing is another, carrying two bracket-shaped projections or snugs of three-inch metal, which by falling upon spring beams at the termination of the outdoor stroke, support the plunger-pole and weights. The plunger is hollow, its external diameter being two feet nine inches, and its internal diameter about two feet three inches; the pump barrel is about three feet in diameter, its metal being two and an eighth inches thick. The valves are on the principle of Messrs. Harvey and West's double-beat valve, the lower seating being two feet ten and a half inches in diameter, and the upper beat two feet three and a half inches; a collar prevents the valve from rising too high, the collar itself being retained by a three-inch rod, screwed through the top of the valve chamber.

Both the valve chambers are four feet three inches in diameter, the depth of the tank around them is about seventeen feet two inches, the bottom of the tank is of two and three-quarter inch metal, the sides at the lower part of three-quarter inch metal, and at the upper of five-eighth inch. The valve chambers are two and an eighth inches thick, the water from the discharge valve passes through a three-foot pipe to the stand pipe, the plate with which it is connected being one inch thick. The

spring beams on each side of the plunger each consist of seven beams, fifteen inches wide and six inches deep, with a bearing between the supports of about six feet nine inches, the supports consisting of hollow columns of two-inch metal. The distance between the spring beams on the two sides is six feet nine inches, the anchoring girders for the parallel motion are eighteen feet long, one foot six inches deep, and one foot ten inches deep over the points of support; they are cast-iron trellis girders of one and a half inch metal in the webs, the centre to which the parallel motion is anchored is five inches diameter and three at the extremity, and the distance between the parallel motion bars is seven feet four inches. The outside diameter of the exhaust pipe is about one foot ten, of the condenser about three feet six, and of the air-pump about three feet three. The action of the engine is as follows. Suppose the engine to be at the top of its stroke, then, when the cataract which governs the steam and exhaust valves descends, the catches will be released and those valves will open, when a down stroke will be made, during which the same cataract will be raised and the steam and exhaust valves closed—and at the same time the plunger will be raised, filling the pump barrel with water; the air-pump will also draw a certain quantity of water from the condenser. The engine will then pause until the other cataract releases the equilibrium valve, when the weights on the plunger-pole will cause it to descend, closing the equilibrium valve, raising the second cataract, and drawing the piston to the top of the cylinder—the air-pump bucket being depressed so that the water, &c., drawn from the centre during the up stroke of the pump, passes through the bucket, the water in the main pump being at the same time expelled through the discharge valve. It must here be observed, that in the Cornish pumping engines the injection cock, which admits condensation water, is not constantly open, but is opened by the valve gear, and remains closed during the outdoor stroke.

This description applies to the engine as originally erected, but now the pump plunger is being enlarged; the intention being, I believe, to work with steam of higher pressure. Before taking leave of the Cornish engine it may be desirable to give some account of its management. When it is desired to start

an engine after it has been at rest for some time, it is necessary to work it for a few strokes by hand, and at first it will fail to complete the indoor or down stroke of the piston on account of deficient vacuum, wherefore the exhaust valve will not be shut by the tappet, which will not reach it. The equilibrium valve is now gradually opened, and the engine goes slowly out of doors; when the equilibrium valve is closed, first the exhaust and then the steam valve is allowed to open, and so on, until the engine assumes its proper stroke. Any variation of the steam pressure will of course be accompanied by varying strokes, but this must be counteracted by working the governor valve; and the length of stroke may be accurately judged by observing how far the tappets travel along the handles after closing the valves. It will from the above be evident that these engines require constant attention, as otherwise they might miss stroke if the steam fell short; when the steam stroke is too long, catch-pieces strike upon the banging-boxes, and ring a bell to call the engineman's attention to the fact.

In the new pumping engine which is now in course of erection at the Scarborough Waterworks, under Mr. Wicksteed's superintendence, surface condensation is employed. This is, we believe, the first application of a surface condenser to a Cornish pumping-engine.*

In the ordinary Cornish engine only one cataract is used, and the plug-rod in descending shuts the steam and exhaust valves, and releases the equilibrium valve; hence there is no pause between the down stroke and the up stroke, and the injection valve is also wrought by an arm attached to the exhaust valve weigh shaft.

Our next example is the Boulton and Watt pumping engine erected at the East London Waterworks, under the superintendence of Mr. Wicksteed. Plate XX. is a longitudinal section of the engine. It will be observed that a piston pump is here employed, the water being drawn into the pump barrel during the up stroke

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* We are not at liberty to give any particulars of this condenser, as Mr. Wicksteed is, we believe, about to publish an account of the new engine at the Scarborough Waterworks in a treatise on Pumping Engines, which will shortly appear.

of the steam piston, and forced into the mains during the down stroke of the same. This is the principal difference between this and the Cornish engine, but the details of the two engines also differ. It will not, however, be necessary here to give a complete description of this engine, as from our previous remarks the section will be readily understood, and will give all the information that is requisite.

CHAPTER XIX.

ON ROTATIVE ENGINES.

In the present chapter we propose to illustrate two rotative engines, one of which is a beam engine, and the other a horizontal engine on Woolfe's principle, used for pumping.

Plate XXI. is a longitudinal section of a beam engine; the cylinder is cast with the bottom upon it, in the centre of which is left an aperture to admit the boring-bar, this aperture being subsequently closed by a door, as shown. The upper end of the piston is attached to an ordinary parallel motion, jointed to the main beam, which beam is carried by a gudgeon working in bearings supported by a large hollow column; beyond this gudgeon the air-pump rod is attached, and at the further end of the beam is the connecting-rod, the lower end of which embraces the crank-pin. The crank is firmly keyed on to the main shaft, which also carries a fly-wheel and the eccentric, by which the short slide valve, which regulates the admission of steam to and its emission from the cylinder, is worked. A common two-ball centrifugal governor is applied to this engine.

The usual cold water and feed pumps are also applied. It will be observed that the column supporting the entablature to which the parallel motion is anchored, is secured to a thick lug cast on to the cylinder. This, however, should be avoided where possible, as inequalities in the thickness of a casting are very likely to produce defects.

It will be observed that the cylinder of this engine is neither clothed nor jacketed, whereby economy is lost; for both these precautions should be adopted, especially when superheating is not resorted to.

Plate XXII. exhibits a longitudinal section of a horizontal

pumping engine on Woolfe's principle. At the extreme left-hand corner is placed the pump, which is double-acting. From the well rises a vertical pipe, leading into a horizontal pipe, passing in both directions, and having its ends curved at right angles, and surmounted by spindle valves, which are the suction valves of the pump. From the upper side of the pump tubes proceed into a horizontal pipe, and where they join the same the discharge valves are placed. Upon the upper horizontal pipe is placed the air vessel, to equalize the pressure of the water and prevent the occurrence of shocks. To the plunger of the pump is attached the pump-rod, which terminates in a cross-head, carrying guide blocks, moving between guides. To the same cross-head is fixed, by a cotter, a piston-rod, the further extremity of which is connected to the piston of the larger cylinder, shown in the drawing. Abutting upon the larger cylinder and concentric with it, is the smaller cylinder, and upon the two cylinders is placed the slide valve and steam chest, with various passages proceeding from it. The smaller cylinder contains a piston, the rod of which is connected with a cross-head, from which proceeds a connecting-rod to work a crank fixed upon the main shaft of the engine, which main shaft carries a fly-wheel and an eccentric, which works the slide valve. To the cross-head last mentioned is attached a link, through which is wrought a bell-crank, having a long vertical and a short horizontal arm. From the short arm links are carried up to work the air-pump, upon the top of which is placed the hot well, from which water to feed the boiler is drawn by the horizontal feed pump, shown to the right of the air-pump, and worked by a link attached to the long arm of the bell crank. On the left of the air-pump is the condenser, with the exhaust pipe entering at its upper extremity. The round opening shown in the condenser indicates the position of the injection cock.

The action of this engine is as follows. High-pressure steam from the boiler is admitted to the small cylinder, and when the small piston has made one stroke the steam is allowed to escape into the large cylinder, and act by expansion, the communication with the boiler being at the same time cut off, and from the large cylinder the steam passes to the condenser. In order that the pistons may work together, the steam which enters the inner

end of the small cylinder passes thence to the inner end of the large, and *vice versâ*. The action of the pumps is thus. When the air-pump bucket rises, condensation water is withdrawn through the foot valve of the condenser, and on the descent of the bucket the water beneath it passes through the circular valve, which moves upon the air-pump rod; and when the bucket rises, this water is expelled through the circular valve which covers the air-pump into the hot well, whence a portion of it is drawn by the feed pump, which is of the plunger description. The excess of water passed into the hot well escapes through a waste-pipe. The condenser and air-pump are placed in a cold-water cistern.

We have given this as a good example of a Woolfe engine, although, considered as a pumping engine, it is certainly very inefficient, being very inferior (as are all rotative engines) to the Cornish engine, when applied to raise water.

CHAPTER XX.

ON MARINE ENGINES.

The variety of engines used for marine purposes appears to be more extensive than that of any other class, designs innumerable having been originated for screw-propeller engines. Those used for paddle-wheel steamers do not vary so much in design.

Plate XXIII. is a longitudinal section of a side-lever marine engine of the old class.

A shows that end of the sole-plate to which the cylinder is bolted; *B* is the working cylinder, furnished with a piston *C*, rendered steam-tight by metallic packing. To this piston is attached the piston-rod *E*, which passes through a stuffing-box in the cover *D* of the cylinder; the top of the piston-rod carries a cross-head, which is secured to it by a gib and cotter-joint; from the extremities of the cross-head links descend, being jointed at the bottom to the side levers, of which there are two, one on each side of the engine. These side levers are similar in form to the working beam of an ordinary beam engine. One of the side levers is shown partly dotted, and the link which connects it with the cross-head of the piston-rod is also shown dotted. *R* is a parallel-motion link which is attached to a short arm *S*, to which motion is imparted by a link jointed to the side lever. Those extremities of the side levers which are distant from the cylinder are attached by gudgeons to a cross-tail, keyed to the lower end of the connecting-rod *G*; the upper end of the connecting-rod carries bearings, retained in position by a strap secured to the connecting-rod by a gib and cotter joint. These bearings embrace the crank-pin, the crank being keyed on to the main shaft *H*. Close behind the crank the main shaft is supported in bearings carried by a plummer-block, bolted to the framing;

behind the plummer-block is the eccentric, from which a trussed rod passes to a short arm on the weigh-shaft *T*, which carries a double arm, from one end of which the slide valves are suspended by a rod *U*, a counterbalance being placed at the other end of the double arm. The valves are of the *D* form, having packing behind them.

The steam having been admitted to the cylinder, and having caused the piston to make one stroke, it passes through the upper or lower passage, as the case may be, into the condenser *N*, where it is condensed by a shower of water passing through the injection cock, regulated by the handle *F*. The condensed steam and the vapour are subsequently withdrawn through the valve *L* into the air-pump *I*, during the ascent of the air-pump bucket *J*, which is worked by a pump-rod *K*, carried by a cross-head, connected by side links with the side levers. On the descent of the pump-bucket, the water, &c. beneath it passes through the annular valve around the pump-rod; and when the bucket again ascends, the water, &c. upon it is expelled through the clack-valve *M* into the hot well *P*, whence a portion of it is drawn by a feed pump to supply the boiler, the rest passing out through the ship's side. *Q* is an air vessel to prevent shocks. The air-pump barrel and rod are lined with brass, so that they may not be acted upon by the injection water. The passage leading from the condenser to the air-pump is continued beyond it, terminating with a chamber fitted with a shifting valve. There are also furnished bilge pumps worked by the side levers, but not shown in the Plate.

It will be observed that in this engine care is taken that the injection water should not strike against the sides of the vessels unnecessarily; and this is a point worthy of attention, as a jet of water striking an iron plate will not fail to reduce its thickness.

Plate XXIV. represents an elevation and section of a direct-action screw-propeller engine; the air-pump and the cylinder on the right-hand side of the plate being shown in section. The cylinders are placed in a horizontal position, one on either side of the main shaft. Their diameter is very great in proportion to their stroke; the slide-valves are short, being enclosed as usual in a steam chest, or slide jacket. Stout piston-rods pass through stuffing-boxes in the cylinder covers, and terminate in guide-

blocks moving between stout horizontal guide-bars. The guide-blocks are attached to short connecting-rods, which act upon the crank of the main shaft. Each slide valve has a pair of eccentrics and a link to work it similar to those of a locomotive, one being so fixed as to drive the engine forward, whilst the other is adjusted to drive it backward. This link is raised and lowered when necessary, by means of a rack and pinion worked by a hand-wheel. The air-pump is placed vertically beneath the main shaft, and the air-pump rod terminates in a block, working between vertical guides; this guide-block is driven by a short crank, by means of a connecting link, to the head of which two other links are also attached to work the remaining pumps. Upon each side of the air-pump are condensers, upon which the hot wells are placed. The air-pump bucket is furnished with a large annular valve, as shown.

The steam, having done its duty in the cylinder, passes thence into one of the condensers, whence the condensed steam and injection water are withdrawn through the clack-valves at the foot of the air-pump. On the descent of the air-pump bucket the water beneath it passes through the annular valve, and when it again ascends the water is expelled through the upper clacks into the hot wells. The throttle valve is shown in the section of the steam-pipe, above the right-hand cylinder.

The foregoing is a very fair example of one class of screw-propeller engines, and the principle is very frequently adopted, the screw-propeller of the Great Eastern being driven by engines having horizontal cylinders.

As the space is very confined in which screw engines are required to work, trunk engines are frequently used. Disc engines have also been applied, but have not come into general use. In Stothert's engines the cylinders are placed above the screw-shaft, at an angle of 45° to the horizon.

As in some cases, where the air-pumps are furnished with metal valves, the velocity of the engine is injuriously high, tooth-gear is applied to reduce the speed, the air-pump being driven from a secondary shaft.

CHAPTER XXI.

ON LOCOMOTIVE ENGINES.

The general form of locomotive engines necessarily admits of but little variation, although the details frequently present very different features. Plates XXV. and XXVI. are illustrative of a locomotive engine constructed by Messrs. Robert Stephenson and Co., for the York, Newcastle, and Berwick Railway. The former being a longitudinal section, and the latter a horizontal section.

The engine, it will be observed, is based upon stout framing, carried upon six wheels, the centre pair acting as driving wheels. The boiler of this engine consists as usual of two parts, the fire-box and casing, and the barrel. The fire-box is about three feet six inches wide, by three feet nine long, and five feet deep; the casing around it being four feet three inches wide, four feet six inches in length, and six feet nine in height; the fire-box and casing being stayed together by 394 ties. The fire-bars which form the grate are placed close to the bottom of the fire-box, being eighteen in number. The crown of the fire-box is strengthened by nine ribs, each of which is five inches deep at the centre and three inches at the extremities, attached to the crown of the fire-box by nine bolts. The flame and gases pass from the fire-box to the smoke-box through six rows of tubes, about one and a half inches in diameter. Above the fire-box and proceeding from the casing is the steam-whistle, also the safety-valves, and over the centre of the barrel of the boiler is the steam dome, within which rises the steam-pipe as shown, the end of which is covered by a slide, wrought by an arm fixed upon the extremity of a shaft which passes through a stuffing-box at the back of the boiler, where a handle is attached to it to regulate the admission of the steam to the engine. A short passage from the

fire-box to the casing, closed by a fire-door, affords the means of supplying the fire with fuel. The boiler, which is well clothed, is attached to the framing by plate and angle iron brackets. The cylinders are placed in the smoke-box; the horizontal steam-pipe from the boiler terminating in a breeches-pipe, the extremities of which communicate with the steam-chests which are placed outside the cylinders. Between the cylinders rises the blast-pipe, which terminates just below the chimney. The pistons carry piston-rods, which terminate in forked heads, through which a gudgeon passes carrying at its extremities guide-blocks, sliding between horizontal guide-bars, the extremities of these guide-bars being bolted to the brackets previously alluded to. The guide-block gudgeon is embraced by the smaller end of the connecting-rod, of which the larger extremity embraces the crank-pin, both ends being furnished with suitable bearings. The cranks are forged upon the driving-axle, and outside them are bearings carried in an axle-box, placed between horn plates, as shown, and vertically acting upon springs by which the weight of the engine and boiler is partly sustained. The driving-wheels, which have plain tires, are placed directly outside the axle-boxes, and beyond the wheels are the back and forward eccentrics, the rods of which are jointed to the extremities of a link, and as this link is raised or lowered, one or the other eccentric is caused to work the slide-valve in the manner already explained. This link is connected with one end of a double arm attached to a weigh-shaft, and to the other end of the arm is fixed a weight to balance that of the link.

From one of the eccentrics of each pair proceeds a link by which a feed pump placed at the side of the fire-box is worked, this feed pump being of the ordinary plunger description, and drawing water from the tender to supply the boiler.

The leading and trailing wheels of the engine require no special explanation, being of the ordinary description. The admission of water to the feed pump is regulated by a stop-cock. The boiler is furnished with the usual water and pressure-gauges and gauge-cocks, and the cylinders with blow-through cocks. To the front of the framing buffers are attached, also fenders, to clear the line of obstacles.

Some locomotives are furnished with donkey engines to supply

the boiler with water while the engine is standing still. The furnaces are frequently arranged to burn coal without emitting smoke, and the exhaust steam is sometimes caused to pass through the feed water before being discharged from the chimney. Means are also supplied to pass the surplus steam into the feed water when the engine is standing still.

For some time a new description of locomotive engine has been somewhat extensively employed on a northern French line of railway, and it is said with considerable success. In this engine the heated air and gases from the furnace, after traversing the tubes through the barrel of the boiler, return through other tubes on the top of the boiler, thereby superheating the steam. The funnel finally rises almost above the foot plate. Some of these engines are furnished with four cylinders, two at each end of the framing.

CHAPTER XXII.

ON ROAD LOCOMOTIVES.

COEVAL with Watt's great improvement in the steam-engine was the attempt to apply steam power to propel carriages on ordinary roads, and many inventors made strenuous efforts to obtain results of practical utility; but so great were the difficulties which must be surmounted before arriving at the desired end, and so inefficient the means at disposal to overcome such obstacles, that the subject gradually ceased to absorb so much of the attention of scientific men, whose energies were turned to such branches of constructive art as appeared to promise more certain and more speedy remuneration; so that after the experiments of Murdoch, Trevethick, Gurney, Hancock, and some others, but little was heard of local locomotion until the subject was again brought before the public a few years since. The stagnation which existed for a time in this interesting department of engineering is probably due to the great interest excited on behalf of the railways; for we find, as the novelty of the latter passed off, and as railways became a part of the every-day system of life, that traction engines, steam-carriages, and agricultural locomotives, began to reappear under more auspicious circumstances than had hitherto been attendant upon their application to practice.

The introduction, however, of steam-carriages and traction engines into general use, was by no means so easy as it might at first sight appear, the practical difficulties being materially increased by want of experience; the mechanical facilities now at the disposal of engineers of course obviated some of the inconveniences, but it is now evident that theory, however well considered, or however accurate in itself, is utterly useless when

applied to our present subject. Experiments alone could supply the requisite information, and as no available experience had been had, numerous experiments were found necessary, each being costly, and most of them unsatisfactory. We will now refer to the principal impediments which have from time to time arisen.

When locomotives made their second appearance upon our roads a cry was raised by the public that horses meeting or passing them would be terrified. This objection would probably have occupied but little attention, had the public been acquainted with the real difficulties of a mechanical character; and moreover, the opinion has proved incorrect, so far as the metropolis is concerned, where the ordinary bustle of traffic was sufficient to prevent the noises of exhaust steam and machinery in motion from attracting special attention, though there may be some danger of accidents from this cause on country roads and lanes.

The arrangement of the machinery must of course depend upon the vicissitudes to which it will be subjected, and which arise from the inequalities of the roads on which the engine is destined to work. The road will of course be liable to elevations and depressions, the effect of which will be, to raise one or both of the driving wheels, hence the machinery will be strained. The commonest method of drawing has been as follows. The engines are fixed on the top of the boiler, and drive on to a shaft carrying spur wheels, which act either directly or through intermediate gearing upon the driving wheels, which were attached to the framework by springs. The result of this arrangement was, that if both driving wheels rose, the distance between the centres of the toothed wheels was altered, and the teeth frequently broken; and, on the other hand, if one wheel alone rose through passing over an obstacle, an amount of cant would be brought upon the shafting, giving rise to a vast amount of friction, and occasionally resulting in breaking the cranks. The means of overcoming such difficulties as these do not appear very obvious, but we shall presently have occasion to refer to some engines in which even these grave obstacles are surmounted by an ingenious disposition of the machinery. Another point requiring some consideration is the means of securing sufficient adhesion between the roads and the peripheries of the driving wheels of the engine, which, however, does not present any

serious impediment to the progress of this department of mechanical engineering. We will now mention some of the principal characteristics of the most important engines which have yet appeared.

Boydell's traction-engine was one of the first that appeared; the wheels were furnished with shoes, suspended from its periphery by iron loops, so that each shoe came down in turn upon the ground, and formed a rail over which the engine could run, the shoe being raised off the ground as soon as the wheel had left it, the series being called an endless railway, and enabling the engine to pass over soft or rocky ground with comparative ease, at the same time insuring sufficient friction to prevent the wheel from slipping.

Another traction engine, well known, is Bray's, and the most remarkable feature about this machine is, that the wheel is furnished with moveable teeth, the object of which is to give a greater hold upon soft or sloppy soil; these teeth only project to their full extent at one point of the periphery of the wheel, and at a point diametrically opposite the teeth are not visible. These teeth are attached to arms acted upon by an eccentric placed upon the axle of the driving shaft, and according to the position in which this eccentric is placed, being adjustable by a worn wheel and tangent screw, so the teeth are caused to project at any desired part of the periphery of the driving wheel. When running over a hard road, the teeth are not required to act, wherefore they are caused to protrude at the upper part of the wheel, whereas, if the ground be soft, they are caused to protrude at or near the bottom of the wheel. In running over soft clayey ground masses of clay adhere to the teeth, but as the latter are gradually drawn into the wheel through slots in the tire, this clay is cleaned off. There is one great disadvantage attending the use of teeth as above described, which is, that a considerable amount of power is absorbed in overcoming the friction of the teeth.

Some notable improvements were introduced into Longstaff and Pullan's traction engines, in which the engines were carried upon vibrating frames, the gearing being always kept in its right position by means of a species of link called a sling. This engine was also heated with Pullan's super-heater, whereby superior economy was obtained.

Very frequently the ordinary spur gearing described above has been dispensed with, motion being transmitted from the driving pinion to the driving wheel by means of a chain.

Messrs. Pullan and Lake have recently patented some improvements of a very practical and extensive character in traction engines and road locomotives, which, indeed, appear to combine all the qualities desirable in a traction engine. A side elevation and an end view of Messrs. Pullan and Lake's agricultural locomotive, is shown at Plate XXVII. The cylinders are mounted on the top of the barrel of the boiler, as shown, the piston-rod head being guided by means of a short tube, moving on a horizontal round bar. From these piston-rods proceed connecting-rods to a main shaft of the usual form, which is furnished with a fly-wheel, as the engine is intended to drive thrashing machines and other agricultural machines. In the end elevation the crank shaft and counter shaft are omitted, their positions being indicated by the dotted lines. This engine is furnished with gearing arranged to give two speeds; the position of the gearing is shown in the drawing. Suitable clutches are furnished for working this gear. The driving wheel is caused to rotate by means of a chain acting upon a toothed wheel, as shown. This chain is liable in the course of time to yield and become loose, wherefore it is necessary to have some means of increasing at will the distance between the counter-shaft and the axle of the driving wheel, and such means are supplied by the following arrangement. The axle of the driving-wheels is carried by an eccentric, which may be caused to revolve by means of a tangent screw placed beneath it, and by means of this eccentric the driving chain can be tightened at will. The engine is furnished with a common governor, for use when it is acting as a stationary engine, and which may/be disconnected when the engine is running. The reversing gear is similar to that of an ordinary locomotive, and the driving wheels carry plates on their peripheries intended to give a better hold upon theroad. These wheels may also be supplied with teeth, which may be withdrawn when necessary bymeans of a screw; thus we have the advantage of having moveable teeth without the friction inherent to Bray's arrangement. Behind the driving wheel and just above the eccentric, is shown in dotted lines the feed pump, and about two feet farther, towards

the hinder part of the engine, is shown an outside pump, in connexion with which is a three-way cock, by means of which the pump can be used to fill the water-tank or the boiler, or to expel water through a jet, after the manner of a fire-engine. This engine is also sometimes furnished with the super-heater above alluded to. The engine is steered by means of apparatus placed in front of the boiler, motion being imparted from a hand-wheel through suitable bevel wheels, and a pinion to the toothed segment upon the driving axle of the leading wheels; when it would be more convenient to dispense with the steering apparatus, the latter can be removed by withdrawing it from the socket in which the bar supporting it is keyed, hence this machine may be used either as a common portable engine, drawn by horses, or as an agricultural locomotive engine.

In Pullan and Lake's traction engine, patented at the same time as the locomotive above described, many advantages are combined. The engines are carried on a frame distinct from the boiler, and are protected from the weather by suitable covering; gearing is used for driving, in place of the chain described above, and a most beautiful and ingenious arrangement is adopted in the construction of the driving wheels, which secures the gear against breakage. The wheels are also furnished with teeth, which may be caused to act or not by a simple adjusting contrivance, of which there are many varieties. The result of the form of this engine is such that it is quite safe in running over any ground; for, if the axis of the driving wheels be canted in one direction and that of the leading wheels in the other, no dangerous results would ensue. Two or three of these engines have already been made, and have been found most efficient, some of them having been furnished with super-heaters and some with contrivances to prevent the boiler from priming.

CHAPTER XXIII.

ON STEAM FIRE-ENGINES.

THE constant increase in height and other dimensions of the buildings in our large towns, has long called for more efficient means of extinguishing conflagrations than those supplied by the ordinary hand-engines. This necessity appears lately to have been better understood than before, and consequently steam fire-engines are gradually coming into extensive use.

For many years the floating fire-engines were the only ones in the metropolis worked by steam, but some time since, one of Messrs. Shand and Mason's steam fire-engines was supplied to the London Fire Brigade. This engine has a short upright boiler and a horizontal cylinder, acting direct upon the pump. Upon the piston-rod is forged a slotted link, and in the slot moves a crank-pin, being part of a crank attached to a shaft, and carrying a fly-wheel and the usual gear for working the slide valve, &c. This engine is always kept ready for service, the water in the boiler and also the steam cylinder being kept hot by gas burners, so that in a very few minutes steam can be raised to work the engine. This engine must be looked upon in the light of an experiment which has proved eminently successful, having done good service at many metropolitan fires under the superintendence of Mr. Gerrod, the engineer to the Brigade.

Messrs. Shand and Mason have made many improvements in the engines constructed subsequently to that above mentioned, and there seems to be but little doubt of steam fire-engines coming extensively into use.

A short time since Mr. Wellington Lee, of the firm of Lee and Larned of New York, imported an American steam fire-engine,

which was tried at Mr. Hodge's distillery, under Mr. Lee's superintendence. The boiler is constructed with a view to raising steam rapidly, and in this it proved eminently successful.

An objection has been raised by some to horizontal pumps, on the ground that any grit in the water will settle upon and injure the lower part of the internal surface; but this has been contradicted, as some horizontal pumps which have been at work with foul water for some considerable time have remained uninjured. But it is certain that grit may be injurious under some circumstances, as was experimentally proved by Mr. Roberts, who caused a fire-engine to be worked with water containing a sediment, which was kept constantly stirred up while the experiment lasted, that is to say, for about twenty minutes, when it was found that the surface of the pump was much injured.

We have selected, as an example for illustration, a fire-engine of peculiar construction, manufactured by Messrs. Silsby, Mynderse, and Co., of New York. A side elevation is shown in Plate XXVIII.

It is furnished with an upright boiler of the multitubular description, containing three hundred one and a quarter inch tubes. In the lower part of the chimney is placed a fan or blower, which receives its motion from one of the hind wheels of the engine by means of a band, the object of which is to create a draught and raise the steam rapidly, while the engine is being drawn to the spot where its services are required. At the back part of the carriage and behind the boiler is fixed a rotary engine, constructed according to Holly's patent; which engine causes a shaft to rotate, the shaft passing nearly the entire length of the carriage and driving a pump constructed on the same principle as the engine, and fixed close behind the driver's seat in front of the chimney. Just below the boiler in front of the framework, is fixed a rotary donkey engine and pump combined, similar in every respect to the main engine and pump, and intended to supply the boiler with water when the main engine is at work. An ordinary feed pump is geared by ordinary bevel wheels to the main shaft. The steam-pipe is seen proceeding from the top of the boiler in a curved form down to the rotary engine, and the exhaust pipe is seen passing from the boiler upwards to the funnel. The usual steam whistle, safety valve, and other valves and gauges are

applied to the boiler; the engine is supported by india-rubber springs. A heater is furnished to heat the feed water passing to the boiler. The weight of the engine is from two to two and a half tons, and it is said to be capable of throwing a one and a half inch stream of water to a distance of a hundred and seventy feet, when working at a pressure of about fifty pounds on the square inch.

APPENDIX.

THE ANALYSIS OF IRON AND IRON ORES.

INTRODUCTION.

A FEW general remarks on the examination of minerals may not be unacceptable to some of our readers, wherefore we offer them in the form of an introduction.

We shall take it for granted that our readers are acquainted with elementary chemistry, and also that they have some notion of analytical chemistry; and we shall, on this account, be very brief as regards details, and refer those who may require instruction in manipulation to the excellent works of Dr. Faraday and Greville Williams, Esq.

It may be well here to observe that our object in the following pages is not by any means to attempt to uphold new or unestablished theories, but rather to afford such information as may be *practically* useful; wherefore we shall only make use of such hypotheses as long experience has proved most convenient for the explanation of those varied reactions upon which the phenomena of inorganic chemistry depend.

As the minerals upon which we shall have to operate generally occur in masses, and never in a powder sufficiently fine to require no further pulverization, we may give as the first step in the actual analysis of any ore, that it is to be finely pulverized, in order that it may be readily acted upon by those reagents with which we purpose to treat it. To effect this pulverization a pestle and mortar will be requisite, consisting of Wedgwood ware, porcelain, steel, or agate, according to the hardness of the mineral which is being examined.

We may divide the examination of metallic ores under two heads:

they consist of complete analysis, or the determination of all or most of the constituents of the ore examined, under the first class; and the second class of analyses consists in the determination of one element only.

The examinations included in the second class are conducted by two methods, the dry way and the wet way; if the former method be adopted, the reactions are produced between the mineral treated and the reagents used, by the assistance of a high temperature, no solvent being employed in the process except such as act as solvents when fused; this method, however, we do not purpose considering in the present work. In the employment of the second method the elements are caused to act upon each other by being in solution, though in some stages of these operations heat has to be resorted to, without using at the same time any solvent.

We can only conclude that the advantage gained in using solvents at a given temperature, when elements are required to act upon each other, is due to the finely divided state in which the bodies are brought into contact with each other, for we find that some substances, which will not act upon each other when solid, will do so slowly and at ordinary temperatures when finely powdered, and far more rapidly when they are dissolved. Let us now consider the solvents which we may be likely to require in our various operations hereafter to be described.

Water is doubtless the most important of all solvents, for without it we should have but few others; thus sulphuric acid, hydrochloric acid, nitric acid, and ammonia are, for instance, but solutions of those substances of which they bear the names.

There are but few minerals which can be advantageously treated by pure water as a solvent, though they may mostly be decomposed by hydrochloric acid, or by a mixture of hydrochloric and nitric acids, which is called aqua regia. Hence we see that although some substances may not be dissolved in water, they may be dissolved when that solvent also contains some other body, such as hydrochloric acid gas, &c., &c.; though it is true that it very frequently happens that the body to be dissolved first combines with the body already dissolved in the water; or at all events, if the solution be evaporated to dryness, the two bodies will be found in combination with each other.

The most usual solvent employed in the examination of metallic ores is hydrochloric acid, assisted in many cases by the powerful oxidizing agent, nitric acid; for we may here observe, that until a body is reduced to the condition of an oxide, it cannot be acted upon by acids, as in all cases oxygen is concerned in the reaction.

There are other bodies besides acids which assist in the solution of

various substances. Thus, although oxide of copper cannot be dissolved in pure water, it dissolves readily in ammonia, which is an aqueous solution of ammoniacal gas.

Again, alumina will not dissolve in pure water; but it may readily be dissolved in a solution of caustic potassa.

We have now given examples of the solution of substances in acids and alkalies, but salts are also useful in some cases. Thus protoxide of manganese may be retained in solution by chloride of ammonium.

When an oxyacid acts upon a base an action is produced which may be illustrated by the following example. If oxide of iron be operated upon by sulphuric acid, which contains one atom of sulphur and three atoms of oxygen, sulphate of oxide of iron is produced by the combination of the two; but if it be acted upon by hydrochloric acid, which consists of one atom of hydrogen and one of chlorine, chloride of iron is formed by the union of metallic iron with chlorine, whilst the hydrogen of the acid combines with the oxygen of the oxide to form water; thus the effect of a hydracid is very different from that of an oxyacid.

We may therefore say that oxyacids combine with oxides to form one compound; whereas, when an hydracid acts upon an oxide, the radical of the acid combines with the metallic base of the oxide to form a haloid salt.

We will next mention the recovery of a solid body from a solution.

This may be performed in a variety of ways. Thus we may recover substances from a solution by evaporating it to dryness, also by withdrawing or expelling the substance by which it was retained in solution; or finally, by combining the body to be recovered with some element which forms with it an insoluble compound.

If we have oxide of copper dissolved in ammonia, we may recover it by combining the ammonia with an acid, when it will be neutralized, and the oxide of copper will be found at the bottom of the vessel.

Water containing free carbonic acid will dissolve a portion of carbonate of lime; but the free acid can be expelled by boiling, or by filtration through some substance, when the carbonate of lime will be precipitated to the bottom of the solution.

Let us take some examples of the third method of recovering substances from solution.

Acetate of lead is soluble in water containing a slight quantity of free acetic acid; sulphuric acid is soluble in water. If sulphuric acid be allowed to operate upon acetate of lead, the acetic acid is displaced and sulphate of lead is formed; sulphate of lead is, however, insoluble in the water and acetic acid; if, therefore, sulphuric acid is added to a solution of acetate of lead, sulphate of lead will be precipitated

to the bottom of the solution, from which the lead itself may be recovered if necessary.

This result will also be obtained, if a soluble sulphate be added to a solution of acetate of lead, and we find, as a general rule, that whenever two elements capable of forming an insoluble compound are brought together in a solution, that compound is formed and is found at the bottom of the vessel.

It has been proposed, as a solution of the question which naturally arises when we see a compound formed by elements arranging themselves in a way which appears contrary to their strongest affinities to form an insoluble compound, that the bodies dissolved are in motion, constantly interchanging their elementary molecules, in proportions dependent upon the relative affinities of the various elements for each other; during which reaction the insoluble compounds would precipitate whenever they were formed, thus putting the elements contained in them out of the reach of further interchange. But we must not occupy our space with speculations of this nature, although their scientific interest is unlimited, and they may result in discoveries practically useful; for it is sufficient for our present purpose to know that whenever the elements of an insoluble compound are in solution together, that compound will be formed and precipitated.

We will now examine the means at hand by which we may separate the various constituents of compounds which we are desirous of analysing.

Let us suppose, in the first instance, that we have a solid substance, and that we reduce it to a powder, and act upon it with a solvent; say, for instance, that the solid substance contains silica, iron, manganese, alumina, &c., with crystalline carbon. Let us heat this substance in hydrochloric acid, then we may dissolve everything except the carbon; well, if this is the case, the carbon is evidently separated from the other constituents of the body undergoing examination. But we must clear the solution of the insoluble residue. This is effected by filtering it through unsized paper; the crystallized carbon, known as graphite, will remain upon the filter, where it may be washed by pouring distilled water upon it, in order to free it from all traces of the substances in solution in the liquid.

We may then evaporate the solution to dryness, and again act upon it with the same solvent, when we shall find that there will again be an insoluble residue; but this time it will be silica, which may be collected on a filter as the carbon was before.

We shall now have a number of substances dissolved in the filtrate which cannot be extracted in a similar manner; for if these be recovered by evaporation to dryness, we shall find that dilute hydro-

chloric acid will dissolve the whole, leaving no residue behind. We must, therefore, look about for some other method of separating the bodies in solution.

If we now cause the iron in solution to take up as much oxygen as it will combine with, and then nearly neutralize the free acid in solution by the addition of carbonate of ammonia, after which we add ammonia and acetate of ammonia, and boil the liquid, the iron will be precipitated, in combination with acetic acid; this may be removed by filtration, and after some time the manganese will also be precipitated.

Thus we succeed in isolating each constituent of the mineral, and this constitutes analysis. Although we purpose to treat of quantitative analysis only in the subsequent sections of this work, we will nevertheless make a few remarks here upon the means of determining the presence or absence of certain substances in a solution. If to a solution of iron we add ferrocyanide of potassium, the precipitate which forms has a blue colour; hence, if a solution on the addition of that reagent exhibits a blue precipitate, iron is present. But the iron may exist as a persalt or as a protosalt; that is to say, the salt may correspond to sesquioxide or to protoxide of iron.

Let ferricyanide of potassium in solution be added to the solution of iron, then, if a protosalt be present the blue colour will appear, but not otherwise.

If a solution be freed from iron and contain copper, then, on the addition of ferrocyanide of potassium a brown precipitate will be formed. Also, if the solution be neutralized with ammonia, and an excess of that reagent be added, a blue solution will be formed.

If bright iron or zinc be placed in an acid solution of copper, the copper will be deposited in the metallic form.

If oxalic acid or oxalate of ammonia be added to a solution of lime, a white precipitate of oxalate of lime will be formed and deposited.

It is needless to multiply examples, but we see that bodies in solution may be recognised by the colour of the solution or by that of the precipitate formed on the addition of certain reagents.

In a systematic course of qualitative analysis, the experiments must be conducted in such a manner as will allow of the detection of each substance in turn.

The elements also give peculiar tints to flame in which they are volatilized, and each may be identified, even when they are all mixed, if the flame be examined by means of a prism; for, in that case, various coloured lines will appear corresponding to the elements present in the flame.

The quantity of some elements in solution may be determined without separating such element from its solution; but before considering this matter we must examine some other points of importance.

It not unfrequently occurs that the state of the substance in solution requires to be altered, oxidized or deoxidized, as the case may be; although it must not be concluded that in every case the amount of oxygen is actually altered, for we use oxidizing agents to convert protochloride of iron into perchloride; but we might in this case call the reagent a chlorinising agent, as those we employ sometimes generate chlorine.

Thus, if we oxidize by passing through the solution a current of chlorine, or by the addition of chlorate of potash and hydrochloric acid, which will, when heat is applied, liberate chlorine, we may say that the chlorine decomposes the water, releasing oxygen to form peroxide of iron, which is again decomposed by the hydrochloric acid formed by the union of the chlorine with the hydrogen of the water, perchloride of iron being ultimately formed; or we may say that the iron combines with the free, and, in some cases, nascent chlorine, supplied to the solution.

Nitric acid is perhaps most frequently applied as an oxidizing agent, but sulphuric acid, bichromate of potassa, chromic acid, permanganate of potassa, &c. &c., are also applicable.

Sulphurous acid may conveniently be used for the deoxidation of substances in solution, also sulphite of soda. All bodies that absorb oxygen are deoxidizers: as phosphorus, potassium, protosulphate of iron, &c.

We have already stated that some substances may be determined as to quantity without removing them from their solutions; we may take as a fair example of this method, that which is frequently used for the estimation of protoxide of iron.

If permanganate of potassa be added to a solution of protoxide of iron, the former is decomposed and the latter is converted into peroxide; the solution of permanganate of potassa is of a rose tint, which disappears when the salt is decomposed. Let a quantity of permanganate of potassa be dissolved and placed in a burette graduated into one hundred parts; let also a few grains of iron be dissolved in hydrochloric acid, and the permanganate of potassa be added to it, until the tint ceases to be destroyed; then examine the burette to determine the number of divisions which correspond to one grain of iron, when the solution will be ready for use as follows.

Add to the solution containing protoxide of iron the permanganate of potassa, until the rose tint appears; then read off the number of

divisions of the burette required, and by the data obtained from the foregoing experiment, calculate the amount of iron present in the solution. This is Margueritte's method.

The quantity of a substance may also be determined by the quantity of a reagent required to precipitate it.

In some cases it is directed to prepare the normal solution for volumetrical determinations similar to the above by dissolving a given weight of the reagent used in a certain volume of water, but we consider it preferable in every case to test the strength of the solution as above.

We must now mention the manipulations requisite when a precipitate is to be weighed.

The precipitate must be collected on a filter and washed until the washings contain no traces of the substances in the filtrate; or in other words the precipitate must be washed until it is perfectly clean.

In some cases the liquid may be decanted off when the precipitate has subsided, which may then be washed by agitation with water, and finally collected on a filter.

If the precipitate will not bear a high temperature, it, together with the filter on which it is collected, must be dried in an air or water bath at 212° until it ceases to lose weight; the whole is then weighed, and the weight of the filter is deducted from it.

If the precipitate is to be heated to redness, the heat must be continued until the filter is completely consumed, and this may be facilitated by directing a gentle current of oxygen upon it. In this process the precipitate should first be dried, then as much as possible of it should be removed from the filter and placed in the crucible in which the ignition is to be performed; the filter may then be burned and the cinder thus obtained is to be added to the precipitate in the crucible. If the filter leaves an ash, the weight of this, determined by a separate experiment, must be deducted from that of the ignited precipitate.

Some elements are estimated by loss. Thus if we expose peroxide of iron to heat in a current of hydrogen, the oxygen will be withdrawn and the loss of weight of the contents of the vessel in which the operation is performed will be equal to the weight of oxygen originally existing in the peroxide.

This method may also be used for the estimation of iron, which is calculated from the quantity of oxygen combined with it.

ANALYSIS OF IRON ORES AND IRON.

Before detailing the processes which have been found suitable for the examination of various iron ores and iron, it is desirable to give some account of those minerals from which the iron used in commerce is most generally obtained.

Magnetic Iron Ore.—The primitive crystalline form of this substance is the cube; but it also occurs in the form of the octahedron and dodecahedron.

The mineral is somewhat brittle, of an iron-black colour, and leaves a black streak.

The ore is magnetic, and has a specific gravity of about 5; it contains about 70 per cent. of metallic iron, consisting of 69 per cent. of peroxide of iron and 31 per cent. of protoxide of iron.

Magnetic iron oxide occurs in granite, gneiss, mica-slate, clay-slate, syenite, hornblende, and chlorite. This ore also occurs in great abundance in the United States, in the Island of Elba, and the iron-sand of New Plymouth, in New Zealand, consists principally of magnetic oxide of iron; some samples of it recently examined containing about 69 per cent. of metallic iron.

It is from this ore also that the celebrated Danemara iron is prepared.

Specular Iron—Red Hematite.—This ore crystallizes in the fourth system, and most generally appears as a modification of the rhombohedron.

The crystals are of a dark steel-gray colour; opaque unless in very thin laminæ, in which case they are translucent and of a blood-red tinge; it leaves a reddish-brown streak, and has a specific gravity of from 4·8 to 5·3.

Pure specular iron consists of peroxide of iron, and therefore contains 70 per cent. of metallic iron.

Finely crystallized specimens of this ore are found in the Island of Elba; also at St. Gothard, Arendal, Sweden, Framont, Dauphinè, and Switzerland; also in the volcanic districts—as Stromboli and Lipari, Etna and Vesuvius.

Red hematite in reniform masses is found in Cornwall, Ulverstone, Saxony, &c.

Brown Iron Ore.—This ore is a mineral which presents in mass a brownish-yellow colour; but when pulverized it exhibits a yellow colour. Its specific gravity is about 4, and when pure it contains 55 per cent. of metallic iron. It usually occurs in the massive form;

but its structure varies according to the locality from which it is obtained.

This ore consists of hydrated peroxide of iron, and is chiefly confined to the sedimentary formations. This ore is found in Normandy, Berry, Burgundy, Lorraine, &c.

Iron Pyrites.—This substance is never treated for the sake of the iron which it contains; but it is frequently employed as a source of sulphur. It crystallizes in the cubic system, is of a bronze-yellow colour, with a metallic lustre; it leaves a brownish-black streak. Its specific gravity is from 4·8 to 5·1; it is brittle, and strikes fire with steel.

This ore, when pure, contains two equivalents of sulphur and one of iron.

Carbonate of Iron occurs in rhombohedrons and in six-sided prisms, similar to carbonate of lime, from which the crystals differ slightly in the value of their angles.

It is commonly more massive, with a foliated and somewhat curved structure.

This mineral is of a light-grey colour; but externally decomposed, it becomes dark-brown, or nearly black. When pure, this mineral consists of carbonate of protoxide of iron. Spathose iron ore is found in rocks of various ages, and is frequently observed to accompany other metallic ores. Carbonate of iron is, however, most plentifully found in gneiss, greywacke, and the coal formation.

The principal deposits in the United Kingdom are at Dudley, Lanarkshire, Ayrshire, and some parts of Wales.

Chrome Iron Ore.—This mineral crystallizes in the cubic system. It commonly occurs in the massive form; is of an iron-black or blackish-brown colour, and when broken it presents a dull uneven surface. It is slightly magnetic; has a dark-brown streak, and a density varying from 4·3 to 4·5.

Chrome iron consists chiefly of protoxide of iron, alumina, and sesquioxide of chromium. It is ordinarily found in veins traversing serpentine rock. It occurs ordinarily in Styria and in the Shetland Islands.

Amorphous chrome iron is obtained in France, Silesia, Bohemia, and Greenland.

Iron is also a constituent of a very extensive variety of minerals; but we only deem it necessary to mention such as are useful in metallurgy, or are likely to come into the metallurgist's hands. We have therefore, with the exception one or two ores, passed in silence such as are not used in the manufacture of iron.

We will now pass on to describe various methods of estimating iron, of separating it from other bodies, and of performing analyses of various descriptions of iron ores.

Ores, the constituents of which are known, may in many cases require the iron only to be determined; but when such components as sulphur and phosphorus occur, it is highly desirable to determine the proportion in which they exist, as this knowledge will enable us to form an opinion as to the quality of the iron obtained from such ore. In many cases it will be desirable to perform a complete analysis of the ores. Cast-iron and steel are analysed to ascertain the quantity of carbon and other foreign elements contained in them, and it is also desirable to examine such specimens of wrought or malleable iron as may exhibit peculiar properties or great strength, as thereby some valuable information may be obtained.

Estimation of Iron.—In estimating iron it is usual to weigh it in the state of peroxide, which contains 70 per cent. of metallic iron. When this oxide exists ready formed in a liquid, it may most conveniently be precipitated either by ammonia or by carbonate of ammonia; but the oxide must be precipitated from a heated solution, otherwise it will be deposited as a gelatinous mass which cannot be easily purified by washing. If iron exists in a solution, the state of protoxide, it is necessary, previous to precipitation, to convert it into peroxide; which may be effected by boiling with nitric acid or chlorate of potassa, or by passing a current of chlorine gas through it. In the latter case, however, it will be necessary to remove the excess of chlorine by subsequent ebullition of the solution. The iron being peroxidized, may then be precipitated by ammonia.

Chlorate of potassa should only be used when the solution contains hydrochloric acid. The oxidizing effect is due to the liberation of chlorine.

There is some danger of error occurring from the use of ammonia to precipitate the iron, as a slight excess of that reagent will redissolve a portion of the precipitate, thereby vitiating the results.

It is desirable, on this account, where greater accuracy is required, to precipitate the iron in the form of succinate or benzoate, and in some cases as basic acetate. The salt thus obtained is decomposed by heating in a platinum crucible, and then weighed as peroxide. It occasionally happens that the operator is obliged to throw down the iron by means of an excess of caustic potassa; but when this course is pursued the precipitate contains traces of potassa, which can only be removed by long-continued washing. Should the amount of sesquioxide of iron be large, it may most readily be freed from potassa by redissolving the precipitate in hydrochloric acid diluted, and reprecipitating it by succinate or benzoate of ammonia, after carefully neutralizing the solution.

When the solution also contains organic matter, such as sugar,

starch, or some of the vegetable acids, the iron cannot be precipitated either by ammonia or its carbonate, and it must be treated with sulphide of ammonium, which precipitates the whole of the iron as sulphide. To obtain the iron in the state of sesquioxide, this precipitate should be thrown on a filter and carefully washed with a very dilute solution of sulphide of ammonium. This last is added in order to prevent the formation of sulphate of iron, which would be dissolved and carried through the filter, thereby occasioning loss.

When the precipitate has been sufficiently washed, it is digested in hydrochloric acid; the solution is then peroxidized and precipitated by succinate, benzoate, or acetate of ammonia.

Estimation of Iron in Iron Ores.—We will, under this heading, insert various methods of estimating iron which have been proposed as suitable for the determination of iron existing in ores of that metal.

Fuch's Method.—The specimen is to be dissolved in strong and pure hydrochloric acid, and peroxidized, either by adding, cautiously, crystals of chlorate of potassa, or by passing a current of chlorine gas through the solution.

The peroxidation is ascertained by testing with ferricyanide of potassium, which produces a blue precipitate with protoxide of iron but none with peroxide.

The solution having been peroxidized, it is to be boiled for a few minutes in order to expel any excess of chlorine which may exist.

A weighed quantity of pure copper is then introduced, and the boiling is then continued, until the colour of the solution changes to a pale yellow green. When no further change of colour is observed to take place, the flask must be filled up with hot water, and the copper removed, washed in cold water, dried, and weighed.

The loss of weight indicates the amount of chlorine consumed to convert the original protochloride into perchloride of iron; every equivalent of copper and every equivalent of chlorine converting two equivalents of protochloride of iron into perchloride.

It follows that every equivalent of copper corresponds to two equivalents of perchloride of iron in solution; or what amounts to the same thing, to two equivalents of peroxide of iron in the substance analysed; which peroxide of iron contains 70 per cent. of metallic iron.

Taking the equivalent of copper at 31·66, and that of iron at 28, it follows that for every 100 parts lost from the weight of the copper, there exists in the solution 176·88 parts of metallic iron.

This method requires very great care, in order to give results at all approaching the truth, and it is totally inapplicable when the solution contains arsenic.

Margueritte's Method.—This method is based upon the employment of a standard test solution, and on the reciprocal action of the salts of protoxide of iron and permanganate of potassa, whereby a quantity of the latter, exactly proportional to the quantity of protoxide of iron present, is decomposed.

The ore is dissolved in hydrochloric acid, and the metal is brought to the minimum of oxidation, which is done by treating the solution with sulphite of soda, and boiling to expel the excess of sulphuric acid; the solution of permanganate of potassa is now cautiously added, until the pink colour of the test solution appears. And the number of divisions of the burette required to effect this is accurately noted.

The permanganate is decomposed so long as any protosalt of iron exists in the solution; but when it has all been converted into a persalt, the permanganate then added remains undecomposed, and is detected by its colour. The solution must contain no substance that may decompose the permanganate, therefore all the excess of sulphurous acid must be carefully expelled.

Copper and arsenic interfere in this manner with the accuracy of the process, and, according to Dr. Noad, were the only metals found to do so; but a slight modification of the process overcomes these difficulties, which are created by the reduction of the compounds of those metals by the sulphite of soda.

The operation is proceeded with as usual, except that after having expelled the excess of sulphurous acid by ebullition, a piece of pure laminated zinc is added, which, acting upon the hydrochloric acid, disengages hydrogen; arsenic and copper are reduced to the metallic state. When the solution of the zinc is complete, the precipitated particles of arsenic and copper are removed by filtration, and the clear liquor proceeded with as before.

To prepare the permanganate of potassa, 7 parts of chlorate of potassa, 10 parts of hydrate of potassa, and 8 parts of peroxide of manganese, are intimately mixed; the manganese should be reduced to the finest possible powder, and the potassa, having been dissolved in water, is mixed with the other substances, dried, and the whole heated to dull redness for an hour. The fused mass is then digested in as little water as will dissolve the salt, and to this solution is added nitric acid, until it assumes a rich violet tint; it is subsequently filtered through asbestos (an organic filter would decompose the permanganate of potassa) in order to separate the peroxide of manganese suspended in the solution. The solution must be carefully protected from contact with organic matter, even the small particles in the atmosphere affecting it.

To convert the liquor into a standard test solution, a given quantity, say 10 grains, of pure iron is dissolved in hydrochloric acid; when the solution is complete the liquid is diluted with about half a pint of cold water, and the solution of the permanganate of potassa is added until the pink colour reappears, and the number of divisions of the burette requisite to produce this is carefully noted, from which the value of the solution may be readily calculated.

Dr. Penny's Method.—This method is based upon a reciprocal action existing between chromic acid and protoxide of iron, whereby a transference of oxygen takes place, the protoxide of iron becoming converted into sesquioxide, and the chromic acid into sesquioxide of chromium.

The iron in clay-band and black-band iron stone being chiefly in the condition of carbonate of iron, is boiled in hydrochloric acid, in order to convert the metallic salt into a protochloride, and the standard solution of bichromate of potassa is then added, until the solution is peroxidized, which is ascertained by frequently testing it with ferricyanide of potassium; when the blue precipitate is no longer formed the protosalt is entirely converted into a persalt.

The test solution is thus prepared:—44·4 grs. of the salt in fine powder are weighed out and put into a burette, graduated into 100 parts, and the instrument is filled to 0 with warm distilled water.

The burette is then closed by the palm of the hand, and its contents are agitated until the salt is completely dissolved and the solution rendered of uniform density throughout. Each division of the solution thus prepared contains 0·444 grs. of the bichromate of potassa, which Dr. Penny found to correspond to half a grain of metallic iron.

The bichromate must be pure, and should be thoroughly dried by heating to incipient fusion.

Estimation by means of hydrogen.—This method may be employed when all the iron exists as sesquioxide, and no other substance capable of being reduced by hydrogen is present.

The mineral, in a fine powder, is carefully ignited in the air, and then in hydrogen. The hydrogen, which should be quite dry, abstracts the oxygen from the sesquioxide, and the amount of iron contained in the compound may be calculated from the loss of weight.

Sesquioxide of iron contains 30 per cent. of oxygen; therefore, for every 100 parts of weight lost by ignition in hydrogen, the substance examined contains 233·33 parts of metallic iron.

We will now explain various methods of separating iron from other substances.

Separation of Protoxide of Iron from Peroxide of Iron.—Fresenius's

Method.—On the property possessed by salts of the protoxide of iron to resist decomposition by boiling with an earthy carbonate, is based a process for its separation from peroxide of iron, when the two exist in solution together.

When boiled with carbonate of baryta, the salt of the peroxide only is decomposed; the solution, filtered from the precipitated peroxide and excess of carbonate of baryta, is boiled with nitric acid to convert the protoxide of iron into peroxide, which last is precipitated by ammonia after the baryta has been separated by the addition of sulphuric acid.

Rose's Method.—Dissolve a weighed quantity of the mixture in hydrochloric acid; peroxidize the protoxide by boiling with nitric acid.

Then precipitate the iron by ammonia, dry and weigh; the increase of weight upon that of the original mixture is caused by the acquisition of oxygen, which converts the protoxide into peroxide. During the process of peroxidation every two equivalents of protoxide combines with one equivalent of oxygen; hence every 100 parts of increased weight represent 700 parts of metallic iron in the form of protoxide, or 900 parts of the protoxide.

As the quantity of oxygen taken up in this process is exceedingly small, the experiments must be very carefully performed, the error occurring in the increase of weight being multiplied nine times in the final result.

Rose's Method, 2nd.—The mixed oxides are converted into metallic iron, by ignition in a current of dry hydrogen, and the water formed, as also the quantity of iron reduced, is ascertained.

Wood's Analysis.—The quantity of peroxide of iron in a solution of protoxide and peroxide in hydrochloric acid may be determined in the following manner.

The compound is powdered finely and placed in a flask, from which the whole of the atmospheric air is expelled by a current of carbonic acid gas; sufficient hydrochloric acid to dissolve the powder is added and the flask is quickly and securely closed. The solution of the powder being completed, recently prepared and perfectly clear sulphuretted hydrogen water is added in excess, the flask again closed and the whole allowed to remain at rest for some days; the peroxide of iron is reduced to protoxide by the sulphuretted hydrogen, and a proportional quantity of sulphur is deposited. This is carefully collected on a small weighed filter, and washed and dried at a gentle heat; the filter must be protected from the atmosphere during the process of filtration.

From the quantity of sulphur deposited, the amount of peroxide of iron originally present may be calculated.

Every 16 parts of sulphur indicate 70 parts of peroxide of iron.

Fuch's Method.—This method of determining the peroxide of iron is detailed at page 220.

The quantity of protoxide of iron present in the solution of the two oxides may also be determined by the volumetrical method of Margueritte or Penny.

In conducting these various processes intended for the determination of the proportions in which the peroxide and protoxide of iron exist when they are together in a compound, great care must be taken during the solution of the substance to be analysed that no possibility occurs either of the peroxidation of the protoxide, or of the reduction of the peroxide.

Separation of Peroxide of Iron from Protoxide of Manganese.—This may be effected by precipitating the iron from a neutral solution by succinate or benzoate of ammonia, which reagents do not precipitate protoxide of manganese. If any iron exists in the solution as protoxide, it must first be converted into peroxide by boiling with nitric acid, or with hydrochloric acid and chlorate of potassa.

If the solution is acid it must be neutralized by ammonia, chloride of ammonium being added to prevent the precipitation of protoxide of manganese. A slight excess of ammonia may be added, so that a trace of peroxide of iron remains undissolved when the solution is heated.

Succinate of soda, or succinate or benzoate of ammonia, may be used as the precipitant. The precipitate, which is bulky, should be washed with caustic ammonia while on the filter, in order to remove the greater portion of the organic acid, that there may be less risk of reducing a portion of peroxide during the ignition of the precipitate. From the filtrate, protoxide of manganese may be precipitated by soda. Peroxide of iron and protoxide of manganese may also be separated in the following manner :—Dissolve the oxides in hydrochloric acid, and boil the solution with carbonate of baryta or with carbonate of lime; the perchloride of iron is decomposed with precipitation of the peroxide, and the formation of a corresponding quantity of chloride of barium or chloride of calcium; while on the contrary, the protochloride of manganese is not affected by the earthy carbonate. The latter is added to the solution of the two oxides, so long as effervescence, due to the escape of carbonic acid, continues. When effervescence has ceased, the solution is boiled for a short time and then filtered. The precipitate of peroxide of iron, with excess of earthy carbonate, is then dissolved in hydrochloric acid; and if carbonate of lime has been used, ammonia is added, to re-precipitate peroxide of iron, avoiding exposure to the air as much as possible, to prevent the

absorption of carbonic acid and formation of carbonate of lime. If carbonate of baryta has been used instead of carbonate of lime, baryta may first be separated from the solution in hydrochloric acid by sulphuric acid, after which the solution is filtered and the peroxide of iron precipitated by the addition of ammonia.

The solution, filtered from the precipitate of peroxide of iron and excess of earthy carbonate, contains chloride of manganese, and also chloride of calcium or barium. If the former, oxide of manganese is separated as follows:—Chloride of ammonium is first added to the solution (unless it contains a large quantity of free acid) to prevent precipitation by ammonia, which is next added; after which the manganese is precipitated as sulphide by sulphide of ammonium. The precipitate is collected, washed with a very dilute solution of sulphide of ammonium, and dissolved in hydrochloric acid; the solution is then heated until the sulphuretted hydrogen thus formed is completely expelled, which is known by the solution becoming inodorous. The solution is now filtered and the manganese precipitated by carbonate of potassa. The solution filtered from the sulphuret of manganese containing lime (and the same process is effectual, if it contains magnesia) is acidified by hydrochloric acid, boiled to expel sulphuretted hydrogen, and filtered. The filtered solution is then supersaturated with ammonia, and the lime is precipitated as oxalate by oxalate of ammonia or oxalic acid. The separation is also effected in the following manner:—Carbonates of manganese and lime are precipitated by a fixed alkaline carbonate, the solution being boiled at the time of precipitation. The precipitate is ignited at a dull red heat, to convert the carbonate of manganese into manganoso-manganic oxide (Mn_3O_4), and is then treated with very dilute nitric acid: this solution dissolves the lime with effervescence, leaving the oxide of manganese unacted upon, which may be collected upon a filter, washed, ignited, and weighed.

Any trace of manganese dissolved by the nitric acid may be precipitated by sulphide of ammonium, after neutralizing the acid by caustic ammonia.

This process is also suitable for the separation of manganese from magnesia, which behaves in every respect as the lime.

If carbonate of baryta has been used to decompose the chloride of iron, the baryta may be separated by sulphate of soda, which will precipitate sulphate of baryta; the solution may then be filtered, and the oxide of manganese precipitated as carbonate of potassa.

A similar process is frequently used to effect the separation of peroxide of iron from other oxides whose solutions in hydrochloric acid are not decomposed when boiled with carbonate of lime or baryta.

Two precautions must be adopted in this process—1. That neither sulphuric, phosphoric, arsenic, nor boracic acid is present in the solution; and 2. That all the iron exists in the state of peroxide, as salts of the protoxide of iron are not decomposable by carbonate of lime.

Separation of Iron from Cobalt and Nickel.—The solution of iron is then peroxidized, and the iron is then precipitated by succinate or benzoate of ammonia, and the cobalt and nickel in the filtrate are separated by one of the following methods.

Phillip's Method.—Both the oxides are to be, if not already in solution, dissolved in an acid, and the solution supersaturated with ammonia, having previously added a sufficient quantity of chloride of ammonium to prevent precipitation; the solution, which is of a sky-blue colour, is then largely diluted with water which has been previously well boiled to expel atmospheric air: caustic potassa is added to the solution and the vessel is closed with a cork; oxide of nickel is thus precipitated, but the oxide of cobalt remains in solution; when the former has completely settled, the supernatant liquid, which should have a rose-red tint, is filtered off, and the oxide of nickel washed with hot water, ignited, and weighed; the oxide of cobalt in filtrate is precipitated by sulphide of ammonium.

The reason which renders it necessary to use water free from atmospheric air for the dilution of the solution is, that air would cause the formation of peroxide of cobalt, which, precipitating as a black powder, would contaminate the oxide of nickel. The more dilute the solution is, the less easily does the oxide of cobalt become peroxidized.

When much ammoniacal salt is present, a very considerable quantity of caustic potassa is required to precipitate the oxide of nickel.

According to Fresenius, the separation by this method is not perfect, the cobalt invariably retaining a trace of nickel, and the precipitated nickel often containing traces of cobalt.

Liebig's Method.—Hydrochloric acid is added to the solution of the two metals, and then cyanide of potassium, in such excess that the precipitate at first formed is redissolved; the whole is boiled, adding from time to time hydrochloric acid, until hydrocyanic acid ceases to be evolved. An excess of caustic potassa is then added, and the boiling is continued until the hydrated protoxide of nickel is completely precipitated; the solution is then filtered, and the filtrate contains the whole of the cobalt in the form of cobalticyanide of potassium; it is evaporated to dryness with excess of nitric acid, the residue fused, and treated with hot water; peroxide of cobalt remains, which is dissolved in hydrochloric acid, precipitated as oxide, by potassa, and reduced by a current of hydrogen and heat, and then weighed.

Rose's Method.—This process is founded upon the greater tendency of protoxide of cobalt than of protoxide of nickel to peroxidize.

Both metals are dissolved in hydrochloric acid; the solution must contain a sufficient excess of free acid; it is then diluted with a considerable quantity of water.

As cobalt possesses a much higher colouring power than nickel, the diluted solution is of a rose colour, even when a great quantity of nickel is present; a current of chlorine is then passed through the solution for several hours.

Carbonate of baryta in excess is added, and the whole allowed to stand for eighteen hours, being frequently agitated; the precipitated peroxide of cobalt and the excess of carbonate of baryta are well washed with cold water, and dissolved in hot hydrochloric acid; after the separation of the baryta by sulphuric acid, the cobalt is precipitated by hydrate of potassa, and after being washed and dried, is placed in a platinum capsule and reduced by hydrogen gas.

The filtrate from the oxide of cobalt is of a pure green colour, and does not contain a trace of that element. After the removal of baryta by means of sulphuric acid, the oxide of nickel is precipitated by caustic potassa.

Frederick Field's Method.—The method of separating iron from either cobalt or nickel, or both, consists in precipitating the iron by means of oxide of lead (litharge): the process is conducted in the following manner.

The mixed metals are brought into solution as nitrates, and the solution is then evaporated nearly to dryness, water is then added, and also oxide of lead, after which the solution is briskly boiled for ten minutes or a quarter of an hour, the iron is entirely precipitated from the solution, the other nitrates remaining dissolved. After filtration sulphuric acid is added, and the liquid is allowed to stand for sixteen hours to precipitate the lead, after which the nickel and cobalt may be determined as in the last method, but it is preferred to precipitate the nickel, as peroxide by hypochlorite of soda.

The peroxide of nickel, after boiling the solution in which it is suspended, separates as a dense precipitate, and can be readily washed, but the precipitation should be performed in an open vessel, in order to facilitate the removal of flakes from the sides, which are somewhat liable to be formed there. The peroxide is heated to whiteness, and the nickel is then weighed as protoxide. This method appears from the experiments of its inventor to be exceedingly accurate and expeditious.

Separation of Iron from Alumina.—The solution containing the peroxide of iron and the alumina is concentrated by evaporation,

and digested with excess of caustic potassa, in which the alumina alone is dissolved.

Knop's Method.—The above process is used, but with the addition of sulphide of ammonium, to effect complete precipitation of the iron, or when practicable, the two oxides are precipitated by sulphide of ammonium, the precipitate being washed with a very weak solution of sulphide of ammonium, and the alumina is subsequently extracted by potassa, to which a few drops of sulphide of ammonium have been added.

Berthier's Method.—The moist hydrates are boiled with sulphurous acid, when the alumina is deposited, the iron remaining in solution.

To prevent an ochreous deposit from the action of the air, the solution should be boiled in a long-necked flask, and when sulphurous acid ceases to be evolved, it should be filled with boiling water and corked; when it has become cold, the liquid is decanted on to a filter, replaced by boiling water, and finally filtered and edulcorated. Phosphoric acid is carried down by the alumina, but arsenic acid is not.

In the above process, the solution of sulphurous acid may be replaced by sulphite of ammonia, the iron is thereby reduced to protoxide, and the alumina is precipitated.

Separation of Iron from Magnesia.—Chloride of ammonium is added to the solution, in order to prevent the precipitation of the magnesia, but this is not necessary, if the solution of the oxides contains a considerable excess of hydrochloric acid. Caustic ammonia is then added to precipitate the iron as peroxide, which, however, carries down some of the magnesia with it, from which it is freed by again dissolving in hydrochloric acid and precipitating the iron by succinate, benzoate, or acetate of iron. The two solutions of magnesia are mixed, and the magnesia is completely precipitated by phosphate of soda. The whole is then well agitated, and allowed to stand for several hours.

The precipitate is collected on a filter, washed with water containing about one-eighth of ammonia. The washed salt is dried and carefully ignited, together with the filter. The ignited salt is then weighed: it is the pyrophosphate of magnesia, and contains 36·46 per cent. of magnesia.

Separation of Peroxide of Iron from Baryta.—To the solution of the two oxides sulphate of soda is added, whereby the baryta is precipitated as sulphate, and from the filtered solution peroxide of iron is precipitated as above directed.

Separation of Peroxide of Iron from Yttria,—Berthier's Method.—The moist hydrates of the oxides are boiled with sulphurous acid,

whereby the yttria will be deposited, the iron remaining in solution. To prevent the formation of an ochreous deposit from the action of the atmospheric air, the solution should be boiled in a flask with a long neck, and when no more sulphurous acid is disengaged, it should be filled with boiling water and corked; when it has become cold, the liquid is decanted on to a filter, replaced by boiling water, and finally filtered and edulcorated.

Scherer's Method.—To a neutral solution of the oxides, oxalate of potassa is added, whereby the double oxalate of yttria and potassa will be formed, which will gradually appear as a crystalline precipitate, which by ignition is converted into yttria and carbonate of potassa; this mixture is dissolved in hydrochloric acid, diluted with much water, and the yttria is then precipitated by caustic ammonia; it must then be well washed with boiling water, after which it may be ignited and weighed.

Separation of Iron from the Alkalies and Alkaline Earths.—This may be effected either by ammonia or its succinate, but when alkaline earths are in solution with iron, care must be taken that the ammonia used be perfectly caustic, for should any carbonic acid be present, the precipitate would become contaminated with the carbonates of the alkaline earths present in the solution. If the iron is to be separated from magnesia, a sufficient quantity of chloride of ammonium must be added to retain that earth in solution, otherwise it will be precipitated by the ammonia. This precaution will, however, be rendered unnecessary if the solution contains much free hydrochloric acid, as in that case chloride of ammonium will be formed on the addition of ammonia.

Separation of Iron from Silica.—This is readily effected when the bodies are in solution, by evaporating to dryness, and redissolving in dilute hydrochloric acid, when the silica will remain insoluble, and may be separated by filtration, dried, and weighed.

It frequently happens that the silicate cannot, even by protracted boiling, be decomposed by hydrochloric or nitrohydrochloric acid, and in this case it must be decomposed by one of the following methods before it can be brought into solution.

Fusion with an Alkaline Carbonate.—The silicate in the finest possible state of division is mixed in a platinum crucible with three or four times its weight of anhydrous carbonate of soda, or with an equal quantity of well-dried carbonate of potassa, or with a mixture of both. The crucible is then placed in a furnace, and at first heated gently; but subsequently to intense ignition, at which it must be maintained for from thirty minutes to one hour. When the crucible is cool, the contents are dissolved out carefully; the crucible being

placed in a beaker and drenched with water, after which hydrochloric acid is added by degrees, by which carbonic acid will be evolved; the beaker is then covered and heated gently until the whole is dissolved, except, perhaps, a few flakes of silica. If heavy, gritty particles subside, the decomposition has been imperfect, and the experiment must be recommenced on another portion of the mineral.

Fusion with Caustic Potassa.—The finely pulverized mineral is mixed in a silver crucible with four or five times its weight of caustic potassa; the cover is placed on the crucible, and it is then carefully heated to dryness over a lamp, and the dry mass is subsequently heated to redness, after which the contents of the crucible may be dissolved in hydrochloric acid.

Abich's Method.—The mineral is fused with four or six times its weight of carbonate of baryta. The most intense heat is required—no action taking place until fusion has been induced, after which rapid decomposition proceeds, the operation being concluded in a quarter of an hour. No silicate has been found to withstand the action of this agent.

Hydrate of baryta may also be used, and in this case the operation may be conducted in a silver crucible over a good spirit-lamp. Four or five parts of the hydrate deprived of its water of crystallization are mixed with one of the mineral and covered with a layer of carbonate of baryta. The decomposition being complete, the analysis is proceeded with in the usual manner.

Berzelius' Method.—This method consists in attacking the mineral with hydrofluoric acid. The finely powdered mineral is placed in a shallow platinum dish, standing in the centre of a leaden dish about six inches in diameter. The bottom of the dish is covered with a layer about one quarter of an inch thick of a paste made of powdered fluorspar and sulphuric acid. The mineral is slightly moistened and the cover having been put on the dish, it is gently warmed, hydrofluoric acid is liberated, which will, in about one hour and a half decompose about twenty-five grains of silicate. During the process the powder must be moistened once or twice. The decomposition being complete, the powder is moistened with concentrated hydrochloric acid until hydrofluosilicic ceases to be evolved, when the excess of sulphuric acid is expelled by evaporation to dryness, after which the powder may be dissolved in dilute hydrochloric acid, and examined in the usual way.

Separation of Iron from Chromium,—Rose's Method.—To a solution of the metals add tartaric acid, to prevent precipitation by potassa, which is then added, and the iron is precipitated by sulphide of potassium. The filtered solution is evaporated to dryness, ignited, fused

with carbonate of soda and nitrate of potassa. The alkaline chromate thus formed is dissolved, and the chromium precipitated by baryta or lead, and weighed as chromate of baryta or lead. The precipitants are used in the form of nitrates.

Liebig's Method.—The solution is saturated with sulphuretted hydrogen to reduce the iron to protoxide (a few drops of sulphide of ammonium answers the purpose), and it is then thrown down by cyanide of potassium, and an excess of the latter added; the iron then dissolves as ferrocyanide of potassium, but the oxide of chromium remains insoluble, and may be dried and weighed.

Separation of Iron from Lime, Strontia, and the Alkalies.—This may be readily effected by caustic ammonia, which precipitates peroxide of iron only. In the cases of strontia and lime, access of air must be avoided, as otherwise a portion of the lime or strontia might be precipitated as carbonate, and for the same reason, the ammonia must be perfectly pure and caustic.

Separation of Iron from Lantanum and Cerium.—The lantanum or cerium may be precipitated as oxalate by oxalate of potash, double oxalates being gradually formed while the iron remains in solution. By heating to redness the mixture is converted into carbonate of potassa and oxide of cerium or lantanum, as the case may be. The mixture is dissolved in hydrochloric acid, and the solution diluted, after which the oxide of cerium or lantanum is precipitated by caustic ammonia.

Separation of Iron from Carbonic Acid.—The carbonic acid may be evolved by means of a mineral acid and estimated as loss. The operation may be conveniently conducted in the apparatus of Parnell, or of Fresenius and Will: in both, means are provided to arrest the aqueous vapour, which might otherwise be carried off without the carbonic acid. Parnell's consists of a flask, in which is the carbonate and a tube of acid—a tube passes through the cork of the flask and is connected at its outer extremity with a tube filtered with chloride of calcium, to arrest aqueous vapour. The apparatus, when supplied with the carbonate and fitted together, is inclined, when the acid runs from the contained tube, and decomposes the mineral; the last portions of carbonic acid are expelled by heat. In Fresenius and Will's apparatus, two flasks are used, and the aqueous vapour is absorbed by sulphuric acid. Whichever method we adopt, the flasks must be weighed before and after the operation, the difference being the quantity of carbonic acid.

The carbonic acid in carbonate of iron may also be expelled by heat and estimated as loss.

Separation of Iron from Phosphoric Acid.—Phosphoric acid when

free, may be estimated as pyrophosphate of magnesia; chloride of ammonium, ammonia, and sulphate of magnesia are added to the solution, which is then well agitated. The mixture is allowed to rest for several hours; it is then filtered, the precipitate washed with water containing a little ammonia, in which it is almost insoluble; the precipitate is then ignited—first gently, then strongly, to convert it into pyrophosphate of magnesia, which contains 63·54 per cent. of phosphoric acid.

Fresenius's Method.—The solution is boiled, removed from the lamp, and sulphite of soda added, until the colour has become pale-green and carbonate of soda produces a white precipitate: it is then boiled until the smell of sulphurous acid disappears, any excess of free acid is neutralized with carbonate of soda, a few drops of chlorine water added, and excess of acetate of soda. The phosphoric acid is precipitated as perphosphate of iron. Chlorine water is now added until the liquor appears reddish. It is boiled until it becomes clear, filtered hot, and the precipitate washed with hot water. The precipitate contains the phosphoric acid as perphosphate of iron, with a little basic peracetate of iron. The precipitate is dissolved in hydrochloric acid, reduced with sulphite of soda, and boiled with potassa or soda till it is black and granular. It is dissolved in hydrochloric acid and added to the other solution of iron, from which the other elements have previously been separated. The filtered solution contains the phosphoric acid, which is precipitated and treated as above.

Separation of Sulphur from Iron.—Dissolve the mineral slowly in hydrochloric acid, pass the evolved gas through acetate of lead, in a solution acidified with acetic acid; sulphide of lead is precipitated: this is converted into sulphate of lead by digestion in fuming nitric acid; from the weight of the sulphur, the amount of sulphur is calculated.

Bromeis' Method.—The powder is acted on by sulphuric acid diluted, and the evolved gas is passed through an ammoniacal solution of silver, and the sulphur is then weighed as sulphide of silver.

We have now, as far as is consistent with the object of the present work, detailed the various methods of separating iron from those elements with which it is commonly associated in nature, and we will therefore pass on to an account of a variety of methods employed for the complete analysis of samples of iron ores, such as are used in commerce, and of commercial iron.

Analysis of Cast-Iron.—The following method of analysing cast-iron and iron ores is extracted from the published report of the experiments on cast-iron conducted at Woolwich, and ordered by the

House of Commons to be printed, 30th July, 1858. The process was adopted in the examination of numerous specimens, the analyses being performed by Mr. John Spiller and Mr. Arthur Reynolds.

Preparation of the Sample.—Preparatory to its examination, the metal was reduced to a suitable state of division, by boring, turning, or planing; in the case of white iron, it was broken to a coarse powder in a steel crushing-mortar. It was considered preferable to prepare an average sample of the pig by boring across it, so that a fair proportion of the graphite, which was occasionally concentrated towards the centre of the pig, might be included in the sample. The five borings obtained in this way were further reduced when necessary, and thoroughly mixed by trituration in a Wedgwood mortar.

Chemical Analysis.—In the analysis of pig-iron, the proportions of the following constituents were usually determined: manganese, carbon, silicon, sulphur, phosphorus; and in certain cases, metals, such as arsenic, lead, and copper, when their existence in appreciable quantity had been discovered in the ores from which the iron had been obtained.

For this purpose, four portions were usually weighed out:

a. 100 grains for sulphur, carbon existing as graphite, silicon, and manganese;

b. 50 grains for phosphorus;

c. 50 to 100 grains for determining the existence and amount of combined carbon;

d. 500 grains for metals existing in the iron in minute proportions.

Sulphur.—One hundred grains of the iron borings were slowly dissolved in concentrated hydrochloric acid, the evolved gas being passed through a solution of acetate of lead, slightly acidified with acetic acid, the sulphuretted hydrogen disengaged together with hydrogen, precipitated the sulphide of lead, which was collected on a filter, washed, burnt, and subsequently (in the customary manner) converted into the sulphate of lead, from the weight of which the per-centage of sulphur was calculated.

The contents of the flask, after the metal had been fully acted upon, were transferred to a porcelain basin, and evaporated to dryness, the mass digested with concentrated hydrochloric acid, and water afterwards added. The insoluble residue, consisting of silicic acid and graphite, was collected on a filter, the filtrate being reserved for the estimation of manganese.

Carbon as Graphite.—The mixed silicic acid and graphite were separated by the action of a warm solution of pure potassa, when the

silicic acid was dissolved, the graphite, which remained insoluble, was again collected, washed with dilute hydrochloric acid and water, and dried; it was afterwards carefully removed from the paper by scraping with a knife-blade, and transferred to a platinum crucible, in which, after exposure for some time to about 300° F., it was weighed. Upon subsequently burning the graphite in a muffle, it usually left a very small quantity of reddish ash, which was deducted from the former weight.

Silicon.—The amount of silicic acid dissolved by the potassa was recovered in the usual manner by evaporation with hydrochloric acid; the residue was digested with water, collected, washed, dried, and weighed. The amount of silicon in the iron was calculated from the silicic acid obtained.

Manganese.—The hydrochloric acid solution, separated from the silicic acid and graphite, was divided into two equal portions, one of which, representing fifty grains of iron, was always sufficient for the estimation of the manganese. The iron in the liquid having been peroxidized by boiling the hydrochloric acid solution, and adding occasionally a little chlorate of potassa, the acid was to a great extent neutralized by the addition of carbonate of ammonia. Sufficient acetate of ammonia was afterwards added for the conversion of the chloride of iron into acetate, and the liquid was boiled, when the iron was completely separated as insoluble basic acetate.

The filtrate containing manganese was rendered alkaline with ammonia, and after the addition of a few drops of bromine, set aside for about eighteen hours. The hydrated binoxide of manganese, which had separated from the liquid, was afterwards collected, washed, dried, and ignited at a high temperature, when it was weighed as manganoso-manganic oxide (Mn_3O_4), which furnished by calculation the quantity of manganese.

Phosphorus.—For the estimation of phosphorus, fifty grains of the iron borings were acted upon with warm nitro-hydrochloric acid, in a flask with a long neck, and after complete solution of the metal, the contents of the flask were transferred to a porcelain basin, and evaporated to dryness; the residue was moistened with concentrated hydrochloric acid and again evaporated, so as thoroughly to expel nitric acid. The residue then obtained was dissolved in hydrochloric acid, the solution diluted, filtered, nearly neutralized with carbonate of ammonia, and the iron in solution reduced to protoxide, by the addition of sulphite of ammonia to the gently heated liquid, and the subsequent careful addition of dilute sulphuric acid to expel excess of sulphurous acid. Acetate of ammonia and a few drops of solution of sesquichloride of iron were then added, and the liquid

boiled, when the phosphoric acid was precipitated as basic phosphate of sesquioxide of iron, with some basic acetate. The liquid was rapidly filtered, with as little exposure to the air as possible, the precipitate was slightly washed and dissolved in hydrochloric acid, the solution neutralized with carbonate of ammonia, and sulphide of ammonium added; it was then gently heated to insure the conversion of phosphate into sulphide of iron. The latter was afterwards removed by filtration, washed with dilute sulphide of ammonium, and the phosphoric acid was precipitated from the solution in the usual manner as ammonio-phosphate of magnesia, and weighed as pyrophosphate of magnesia, from which the phosphorus was calculated.

Combined Carbon.—After numerous comparative trials of the several methods in common use for determining the total amount of carbon in cast-iron, that which was ultimately adopted (after necessary experiments had fully established its accuracy) consisted in dissolving the metal in an acid solution of chloride of copper, collecting and washing the insoluble residue which remained after the complete action of this solvent, and submitting it, when dry, to combustion with oxide of copper in a current of oxygen, the source of heat employed being the gas combustion-furnace. The total amount of carbon in the iron was then calculated from the weight of carbonic acid absorbed by solution of potassa in the usual manner. The carbon existing in a state of combination with the iron was represented by the excess which this process afforded over that of the direct estimation of carbon as graphite, in the manner already described.

Minute Proportions of Foreign Metals.—About 400 or 500 grains of the iron were employed in the examination for metals precipitated by sulphuretted hydrogen, *e.g.*, lead, copper, arsenic, &c. The iron was dissolved in hydrochloric acid, and the solution, diluted and partly neutralized with carbonate of soda, was submitted to the action of sulphuretted hydrogen. After saturation with the gas, the liquid was allowed to stand at rest for several hours, and the small quantity of sediment which had subsided was examined for metals by the ordinary analytical processes.

Analysis of Iron Ores.—The analytical processes employed for the separation of the various constituents occurring in iron ores, were in a great measure identical with those employed in the examination of metallic iron; thus the estimation of oxide of manganese was conducted in a precisely similar manner, and with the exception that no process of reduction was required in the case of clay ironstone, and other ores containing the iron already in the state of protoxide, the phosphoric acid was determined by the same process as that employed for the estimation of phosphorus in pig-iron. The amount of metallic

iron and its condition of oxidation in the ore were determined by Margueritte's volumetrical method with standard solution of permanganate of potash, while the proportions of lime, magnesia, carbonic acid, water (hygroscopic and combined), insoluble residue, and the nature of this latter, were determined by following the analytical processes invariably employed in mineral analyses of this description.

Analysis of Clay Ironstone,—Parnell's Method.—The ordinary constituents of this ore are, carbonic acid, silica, protoxide and peroxide of iron, alumina, magnesia, lime, and protoxide of manganese. Its complete analysis may be effected in the following manner:—The powdered mineral is boiled in aqua regia, with effervescence of carbonic acid and separation of silica, with perhaps a little alumina as insoluble residue. These are estimated by ordinary processes. The solution, which contains all the bases, with perhaps the exception of a little alumina, is evaporated to dryness: the residue is redissolved in dilute hydrochloric acid, and the solution is filtered. Unless the solution is very acid, chloride of ammonium is now added, and afterwards excess of caustic ammonia, which precipitates peroxide of iron and alumina, with small quantities of protoxide of manganese and magnesia. From the solution filtered from this precipitate lime is to be precipitated as oxalate, by oxalate of ammonia or oxalic acid. The precipitate by ammonia being filtered and washed, is dissolved in a small quantity of hydrochloric acid. This solution is then boiled with excess of caustic potassa, to dissolve the alumina at first precipitated by potash, which may be estimated by the usual method. The portion insoluble in excess of potassa is redissolved in pure hydrochloric acid, the solution is carefully neutralized with ammonia, and the peroxide of iron precipitated as succinate or benzoate, with the precautions already described. The filtered liquid, containing small quantities of magnesia and protoxide of manganese, is mixed with that filtered from the oxalate of lime; and from the mixture manganese is precipitated as sulphuret by sulphide of ammonium from the filtered solution, and after the separation of this precipitate the magnesia is separated as ammonio-phosphate by phosphate of soda with ammonia.

If the amount of iron only is required, add ammonia in excess to the solution in aqua regia; after washing, boil the precipitate in solution of caustic potassa, to dissolve alumina, redissolve the peroxide of iron in hydrochloric acid, and again precipitate it by ammonia; dry, ignite, and weigh.

Analysis of Spathose Iron Ore; Woehler's Method.—Dissolve the powdered mineral in hydrochloric acid, adding nitric acid; during the process, dilute the solution, and neutralize it with carbonate of soda until it becomes of a brownish colour, when a concentrated solution

of acetate of soda is to be added, and the whole heated to the boiling point. In this manner, iron, and iron only, is precipitated, the precipitate being a salt of the peroxide. The filtrate is to be neutralized, mixed with hypochlorite of soda, and allowed to stand for twenty-four hours, when the manganese will be precipitated as the oxide, having the symbol MnO_2. The application of heat transforms it into manganoso-manganic oxide (Mn_3O_4). The liquid filtered from the manganese precipitate should be examined for lime and magnesia.

Second Method.—Dissolve as before, and precipitate all the iron by carbonate of soda, stirring the solution during the process; the other bases remain dissolved in the free carbonic acid. The solution should be much diluted.

Another Method,—Conington.—Dissolve the finely pulverized ore in hot hydrochloric acid, peroxidize the solution by means of nitric acid or chlorate of potassa, then add caustic ammonia, until a precipitate begins to appear, after which precipitate the iron by sulphide of ammonium, filter off the solution, rapidly wash the precipitate with water, containing a few drops of sulphide of ammonium, ignite, and weight it.

Acidify the filtrate with hydrochloric acid, evaporate the solution to dryness, and heat the residue, to volatilize the ammoniacal salts; dissolve again in hydrochloric acid, saturate the solution with chlorine, and precipitate the manganese by caustic ammonia, filter, rapidly ignite, and weigh as usual. The other ingredients are determined as usual.

Analysis of Chrome-Iron Ore.—(*Noad's Manipulation and Analysis.*)—The mineral is first reduced to a fine powder, after which it is to be fused with caustic potassa (an alkaline carbonate is not applicable). The fused mass is digested in water, which dissolves the chromate of potassa, together with the excess of potassa. The oxide of iron remains behind, together with, perhaps, a small quantity of undecomposed ore, which is separated from the sesquioxide of iron by hydrochloric acid; from the solution in hydrochloric acid the iron is precipitated by ammonia, and the chromic acid in the aqueous solution is reduced to sesquioxide of chromium by hydrochloric acid and alcohol.

If the mineral contained alumina, it will be found in the aqueous solution with the alkaline chromate, and will be precipitated with the oxide of chromium, from which it is separated in the following manner.

The mixture of the two oxides is fused with twice its weight of carbonate of soda, and twice and a half its weight of nitrate of potassa. The oxide of chromium becomes converted into alkaline chromate, which is extracted with water, and the alumina which remains undissolved is freed from alkali by solution in hydrochloric acid and precipitation by ammonia.

According to Dr. Schaffhaur, a portion of the alumina in this

process always dissolves along with the alkaline chromate; he therefore recommends to convey the precipitate obtained by adding ammonia to a solution of the two oxides into a hot concentrated solution of caustic potassa, and to boil the whole down until near solidification; when quite cold, water is added, and the whole of the alumina dissolves without carrying with it a trace of oxide of chromium.

Woehler's Method.—The finely powdered ore is intimately mixed with four parts of bisulphate of potassa, and raise the whole to a red-heat; a sufficient time for the complete decomposition of the mineral having elapsed, the mixture is allowed to cool, after which a double quantity of equal parts of carbonate of soda and nitrate of potassa are added, and the mixture is again fused, in order to obtain an alkaline chromate. The mass having been allowed to cool, the alkaline chromate is extracted by water, and the insoluble residue is treated as usual.

Analysis of Red Hematite.—This ore usually contains sesquioxide of iron, some alkaline carbonates, and admixture of the matrix in which the ore is found.

Fresenius's Method.—The mineral is first pounded, and dried at 212° F. Treat the dried mineral with dilute nitric acid, or with boiling acetic acid, in order to dissolve out the alkaline carbonates, which may be estimated in the usual manner, from this solution. Filter off the solution, and dry and ignite the residue as usual, and then place it in a porcelain boat, which is put into a porcelain tube, and heated to redness, whilst a current of dry hydrogen is passed slowly over it. The loss of weight in this last operation expresses the amount of oxygen in the sesquioxide of iron, from which the iron may also be calculated. The residue is then treated with hydrochloric acid, by which the iron is dissolved, and it is then immediately determined volumetrically by the method of Margueritte or by that of Penny. Wash the insoluble residue dry, ignite, and weigh.

The water and carbonic acid may be determined by a separate ignition, being estimated as loss. (In order to determine the quantity of each of these ingredients, the water may be arrested by a tube containing chloride of calcium).

Analysis of Brown Hematite.—This ore usually contains hydrated sesquioxide of iron, alumina, sesquioxide of manganese, lime, magnesia, silica, phosphoric acid, sulphuric acid, and admixture of matrix.

Fresenius's Method.—(Recommended for ores containing only a small quantity of silica, alumina, lime, and magnesia.) Fuse the dry pulverized mineral with thrice its weight of carbonates of soda and potassa. When cold, digest the fused mass in water, filter, and wash the residue. Acidify the filtrate with hydrochloric acid, and separate

the silica; add a few drops of solution of chloride of barium, and let the liquor stand for twenty-four hours, after which filter from sulphate of baryta. Remove the excess of baryta by means of sulphuric acid, and precipitate the phosphorus as pyrophosphate of magnesia in the following manner. To the solution containing the phosphoric acid, add a clear mixture of sulphate of magnesia, caustic ammonia, and chloride of ammonium, until its odour is evolved, and let the mixture stand for twelve hours in the cold; filter and wash the precipitate with water containing one-third of solution of ammonia, until the rinsings after the addition of hydrochloric acid cease to be rendered turbid by chloride of barium; dry the precipitate, place it in a platinum crucible and heat, first gently, then to intense redness, and weigh it as pyrophosphate of magnesia.

Digest the residue in hydrochloric acid, in a flask placed obliquely, until the decomposition is complete; dilute and filter from the residual matrix, which wash, dry, ignite, and weigh.

Determine the sulphuric acid in the filtrate by chlorate of barium. Evaporate the solution to expel excess of acid, dilute, add carbonate of soda, and precipitate with carbonate of baryta; let the liquor stand for half an hour, and then filter. Dissolve the precipitate in hydrochloric acid, precipitate the baryta by sulphuric acid; filter and add ammonia, until the solution is alkaline; filter from the precipitate, which wash, dry, and ignite. It contains sesquioxide of iron, alumina, phosphoric acid, and silica. Digest in hydrochloric acid, and separate the silica, reduce the filtrate by sulphite of soda, and determine the iron, alumina, and phosphoric acid.

Acidify the alkaline filtrate, and boil with chlorate of potassa; separate alumina and phosphoric acid.

In the filtrate determine alumina and the alkaline earths. In this method the presence of copper and arsenic is neglected.

Another Method.—Digest the mineral in hydrochloric acid, and treat the insoluble residue by the first method. Evaporate the solution in hydrochloric acid to dryness, and separate the silica; reduce the filtrate by sulphite of soda, and expel the excess of sulphurous acid by heat; saturate the solution with hydrosulphuric acid; if a precipitate is produced, test it for copper and arsenic. Expel the hydrosulphuric acid by heat, precipitate with carbonate of soda, and add caustic potassa in excess; boil and filter. A black precipitate and an alkaline filtrate are obtained. The former contains oxides of iron, and perhaps carbonate of manganese and carbonates and phosphates of lime and magnesia. Dissolve in hydrochloric acid and separate phosphoric acid with sesquioxide of iron; filter, then separate, and return the sesquioxide of iron to the other solution.

Acidify the solution of alkaline phosphate by hydrochloric acid, and set aside to add to the solution of phosphoric acid.

Treat the filtrate from the phosphoric acid and iron, to separate iron, manganese, lime, and magnesia. Acidify the alkaline filtrate, which contains alumina and phosphoric acid; boil with chlorate of potassa, precipitate by ammonia, and add chloride of barium; digest and filter; the precipitate contains all the alumina and phosphoric acid; the latter is combined with the alumina and baryta.

Wash and dissolve in as little hydrochloric acid as possible, heat, saturate with carbonate of baryta, add soda, and precipitate the baryta by carbonate of soda, and filter. The alumina is in the solution, and the phosphoric acid is in the filtrate.

Acidify the solution with hydrochloric acid, and boil with chlorate of potassa; precipitate by the addition of chloride of ammonium and caustic ammonia; boil, filter, and wash the precipitate; dissolve in hydrochloric acid, precipitate baryta by sulphuric acid, and determine phosphoric acid in filtrate by precipitation by mangnesia.

Determine the sulphuric acid as directed in the first method.

Analysis of Titanic Iron Ore.—Woehler.—Fuse the finely powdered ore with bisulphate of potassa at a red heat; when the fused mass is cool, dissolve in water; saturate with ammonia, and precipitate by sulphide of ammonium the iron and titanic acid.

Wash the precipitate with sulphuric acid, to dissolve out the iron—the titanic acid remains behind as an insoluble white powder.

Another Method.—Raise the powdered mineral to an intense heat in a slow current of hydrogen, to reduce the iron, which may be subsequently extracted by hydrochloric acid.

Analysis of Bog-Iron Ore,—Woehler's Method.—The mineral is dissolved in hydrochloric acid, evaporated to dryness at 212° F., redissolved in warm dilute hydrochloric acid, and filtered to remove the sand and liberated silicic acid.

The solution should then be boiled with sulphite of soda, to reduce the peroxide of iron to the protoxide, and the arsenic acid to the metal (until no odour is perceptible); the arsenic is then precipitated by sulphuretted hydrogen as sesquisulphuret, which may contain copper.

After removing this precipitate by filtration, the solution should be boiled to remove sulphuretted hydrogen, when carbonate of soda may be added, and the whole boiled with excess of caustic soda, until the precipitate is converted to a powder.

The solution, after filtering, contains alumina and part of the phosphoric acid; and the precipitate consists of protoxide and peroxide of iron, carbonates of manganese and carbonates and phosphates of lime

and magnesia. It should be dissolved in hot nitric acid, the solution partly neutralized with carbonate of soda and boiled with acetate of soda. By this process all the oxide of iron and phosphoric acid are precipitated, which may be separated as usual. The filtered solution contains the protoxide of manganese, lime, and magnesia, which may also be separated in the ordinary way.

Analysis of Furnace Slag.—Woehler.—The powdered mineral is digested in hydrochloric acid mixed with nitric acid until it becomes a yellow gelatinous mass, when it is evaporated to dryness on a sand-bath. The residue is digested in weak hydrochloric acid, and the silica removed by filtration is washed, dried, and weighed.

The iron is precipitated from the solution by ammonia. If lime and magnesia are present, they are obtained from the filtrate from the iron precipitate. The lime is precipitated by oxalate of ammonia and is ignited and weighed as carbonate; and the magnesia is precipitated by phosphate of soda, ignited and weighed as pyrophosphate.

Analysis of Meteoric Iron.—Muller's Method.—The powdered mineral is dissolved in dilute hydrochloric acid in a tubulated retort. The hydrogen disengaged is passed through bulbs containing nitrate of copper, in order to arrest any hydrosulphuric acid which may be evolved. The sulphur obtained is oxidized by boiling in nitric acid, and weighed as sulphate of baryta.

The solution is filtered from the insoluble residue and saturated with hydrosulphuric acid; sulphur and a trace of copper are deposited. The solution is oxidized, and the iron precipitated as sulphide, which is, however, partly soluble in presence of phosphoric acid.

The phosphoric acid is estimated by fusing the mineral with carbonate of soda and precipitating it by magnesia.

Nickel, cobalt, and manganese are precipitated by sulphide of ammonium, the iron in this case being separated by carbonate of baryta. The nickel and cobalt may be separated by Liebig's method, or by precipitating the cobalt, by means of carbonate of baryta, from a solution which has been previously treated with chlorine or bromine. The residue is levigated, by which is obtained a black flocculent matter and a black shining substance. The former dissolves in hydrochloric acid, evolving hydrosulphuric acid. The black shining mass dissolves completely in warm nitro-hydrochloric acid; the solution is mixed with soda and carbonate of potassa, and evaporated to dryness, and fused, to remove phosphoric acid. Iron and nickel are determined as above. This is the method which was used by Muller in the analysis of some specimens of meteoric iron from Zacatecas, in Mexico.

GLOSSARY.

Air-condenser.—Is a condenser where air is the cooling medium, steam being contained within the vessel, which may be of tubes or flat plates, around which a current of air circulates.

Air-jackets.—Are air spaces left around steam cylinders and boilers to prevent the dispersion of heat.

Air-pumps.—Are pumps used to remove the air, vapour, and water from the condensers of steam-engines.

Air-vessels.—Are fixed upon the discharge pipes of force pumps to equalize the pressure of water and to prevent the occurrence of shocks.

Argillaceous.—Clayey.

Ball-valve.—A valve formed by a sphere fitting a spherical seat.

Balance levers.—Are weighted levers used to open the valves of Cornish and other pumping engines.

Belly.—The central part of a blast furnace.

Bevel-wheels.—Tooth wheels, having their teeth at an angle to the axis.

Bell-crank.—A lever having its arms at right angles.

Bilge-pumps.—Are used for removing the bilge-water in ships.

Blast-furnace.—An upright furnace used for smelting iron.

Blooms.—Masses of wrought-iron as furnished from the puddling forges.

Blow-holes.—Air spaces which sometimes occur in castings.

Blowthrough Cocks.—Are applied to steam-engines to allow steam to be blown through cylinder and condenser before starting.

Body.—The upper part of the blast furnace.

Boring-bars.—Carry the tools by which cylinders are bored.

Boring-heads.—Short cylinders, which carry cutting tools, and are placed upon boring-bars.

Boshes.—Lower part of the blast furnace.

Boss.—Circular elevations to receive the pressure of nuts, bolt-heads, &c.; also central projections, to which the arms of the wheels, &c., are attached.

Botryoidal.—A term applied to minerals, of which the fracture is conchoidal.

Brine-pumps.—Are used to discharge salt water from marine boilers, at intervals, to prevent super-saturation, and deposition of salt.

Broaches.—Tools for smoothing cylindrical or conical holes.

Buckets.—Pistons fitted with valves to allow of the passage of fluid through them in one direction.

Bucket-pumps.—Pumps furnished with buckets.

Buddles.—Apparatus for washing minerals.

Cams.—Discs upon which bosses or protusions are formed, either upon the periphery or the face.

Carbonates.—Compounds of earth or oxides with carbonic acid.

Carrier.—A piece of apparatus used to secure the revolution of work in a lathe.

Cataract.—A species of brake, which is used to govern the velocity of Cornish pumping engines.

Centre-punch.—A pointed punch used to mark out work.

Chucks.—Apparatus connected with turning lathes, to which the work to be operated upon is secured.

Clack-valve.—A valve opening on a hinge placed at one edge.

Clinkers.—Slags or scoriæ, which form in furnaces.

Clothing.—Covering applied to steam boilers, cylinders, &c., to prevent loss of heat.

Collar-bolt.—A bolt forged with a shoulder or collar.

Cotter-joint, Gib, and.—A joint made with a key and wedge.

Counter.—An instrument for recording the number of strokes or revolutions made by machinery.

Cores.—Pieces of baked earth, used to produce cavities in castings.

Core-prints.—Projections on patterns left to form recesses in moulds, in which to rest cores.

Cross-heads.—Cross beams carried at the upper ends of piston and other rods.

Cross-tails.—Similar to cross heads, but fixed at the lower extremities of rods.

Cupolá.—A small blast furnace, used to melt iron for castings.

Cyanogen.—A gas consisting of carbon and hydrogen.

Cylinder ports.—The steam passages through which steam is admitted to the working cylinder of an engine.

Deoxidation.— Removal of oxygen from bodies with which it is combined.

Detent.—A catch to arrest the teeth of wheels or racks.

Dividing-engine.—A machine to effect the graduation of scales.

Disengaging-gear.—Gear for stopping and starting engines.

Donkey-engines.—Small engines used to feed steam boilers.

Double-beat Valves.—Valves formed with two seatings.

Drifts.—Tools used to clear square and polygonal holes.

Dynamics.—The science which treats of the motion of bodies.

Eccentric.—A wheel fixed eccentrically upon a shaft to produce rectilineal from rotative motion.

Eccentric strap.—A band surrounding the eccentric, and within which the eccentric revolves.

Equilibrium-valve.—A valve so formed that it is unaffected by fluid pressure in either direction.

Exhaust-port.—The opening by which waste steam leaves the working cylinder.

Expansion valve.—A valve used to cut off the supply of steam at any position of the engine.

False seams.—Ridges produced on castings, where the mould is joined.

Feed-pump.—A pump used to supply steam boilers.

Ferruginous.—Containing iron.

Flasks.—Boxes in which moulds for castings are made.

Fluxes.—Materials used to dissove scoriæ and protect surfaces from oxidation.

Fly-wheel.—A heavy wheel employed to equalize the motion of machinery.

Floats.—A kind of file, but having redges instead of teeth.

Gab-lever.—An eccentric rod having a gap to embrace the valve gear.

Galena.—A combination of sulphur and lead.

Gates or *Gits.*—Air and feed holes left in moulds for castings.

Gauge Cocks.—Cocks fixed at various levels in a steam boiler, to show the height of the water level.

Gauge-glass.—A glass tube connected at top and bottom with the boiler, to show the water level at sight.

Gib and Cotter-joint.—*See* Cotter.

Gits.—*See* Gates.

Gland.—The cover of a stuffing-box.

Governor.—An instrument to regulate the motion of a prime mover.

Grease-cock.—A cock to allow of the entrance of grease to steam cylinders, &c., without loss of steam.

Gudgeons.—Short shafts, pins, or studs acting as axes of rotation or oscillation.

Heads.—The standards which carry the centres of a lathe.

Heads-boring.—*See* Boring-heads.

Heads-cross.—*See* Cross-heads.

Hearts.—The vessels making the communications between the various tubes of Craddock's boiler.

Heat, latent.—Heat which has disappeared during liquefaction or gasification.

Heats, specific.—The relative quantities of heat contained by various bodies, of equal weight.

Hob.—A kind of screw used to make dies and screw cutting tools.

Hub.—*See* Boss.

Homogeneity.—Uniformity of texture and constitution.

Horn-plates.—The plates which guide and retain the axle boxes of railway and other vehicles.

Horse-power.—One horse-power is equal to 33,000 foot-pounds of work per minute.

Hot well.—A cistern into which the water, &c., from the condenser of a steam-engine is raised by the air pump.

Indicator.—An instrument for determining the pressure in the cylinder of a steam engine.

Injector, Gifford's.—An instrument for feeding boilers by means of a jet of steam.

Injection-cock.—The cock which regulates the admission of water to the condenser.

Jigging.—Washing minerals in a sieve.

Journal.—That part of a shaft which is in contact with the bearings.

Joule's Equivalent.—The amount of work found by Dr. Joule to be equivalent to one unit of heat, the work being expended in the production of friction—772 foot-pounds.

Junk rings.—The rings by which piston packings are retained in position and tightened up when necessary.

Leading screw.—That screw by which the slide-rest of a screw-cutting lathe is caused to progress along the lathe bed.

Latent heat.—*See* Heat, latent.

Mandril.—The shafts in the head-stock of a lathe which carries the centre.

Manhole.—An opening in a steam boiler to admit a man to clean it.

Matrix.—The soil surrounding a mineral which adheres to it when it is excavated.

Mitre wheels.—Bevel wheels, having their teeth at an angle of 45° to the axis.

Moment of Force.—The intensity of a rotating force, multiplied by its distance from the centre of rotation.

Mud-hole.—An aperture in the lower part of the boiler to allow the sediment to be washed out.

Nozzles.—The extremities of the steam and exhaust passages of the cylinder of a steam-engine.

Oxidation.—The combination of oxygen with any substance.

Oxides.—Compounds of oxygen with various bodies.

Packing.—Metal, indiarubber, or hemp, employed to prevent the escape of steam past the moving parts of an engine.

Pall.—*See* Detent.

Plug-rod.—Rod by which the valve gear of a pumping engine is wrought.

Plummer-blocks.—Carry the bearings of shafts.

Poppet-head.—The back head of a lathe.

Ports.—*See* Cylinder ports.

Power.—Work divided by time.

Prints.—*See* Core prints.

Pump buckets.—*See* Buckets.

Reniform.—Of a kidney shape.

Rhymers.—*See* Broaches.

Riggers.—Pulleys by which motion is transmitted through bands.

Ring-valves.—Double-beat valves, having the two beats in the same plane.

Roasting.—An operation to remove sulphur, arsenic, and other volatile ingredients from minerals to be smelted.

Scabs.—Defects on castings produced by the peeling of the mould.

Shank.—A large ladle used by moulders.

Silicates.—Combinations of silicic acid with various bases.

Slag or Scoriæ.—The refuse from smelting operations.

Snap.—A swage used for forging the heads of rivets.

Snugs.—Projections to afford means of attachment or to fix the position of plummer blocks, &c.

Spur wheels.—Tooth wheels.

Spring beams.—Stout beams that receive the blow at the termination of the stroke of a Cornish engine.

Steam-jacket.—Steam space left around a working cylinder.

Steam-ports.—*See* Cylinder ports.

Sulphates.—Compounds of sulphuric acid with various bases.

Sulphides or sulphurets.—Compounds of sulphur with various elements.

Superheaters.—Apparatus for elevating the temperature of steam above that due to its pressure.

Tang.—That part of a file or chisel that is inserted in the handle.

Taps and Dies.—Tools for making nuts and screws.

Template.—A gauge showing the profile of any required work.

Trunnions.—The journals by which oscillating cylinders are supported.

Tue-iron.—The nozzle through which the blast is supplied to a forge.

Tunnel-hole.—The opening through which a blast furnace is fed.

Tuyer.—*See* Tue-iron.

Valves.—Apparatus to regulate the flow of liquids and gases.

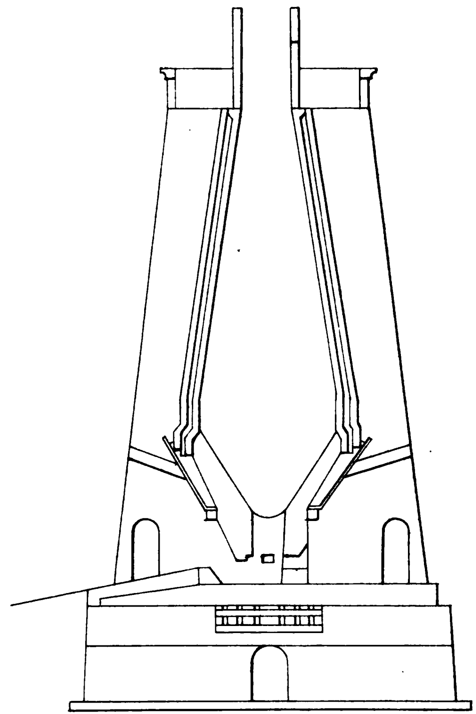
Weld.—A joint made by hammering or pressing metals together when hot.

Work.—A pressure multiplied into the space through which it acts.

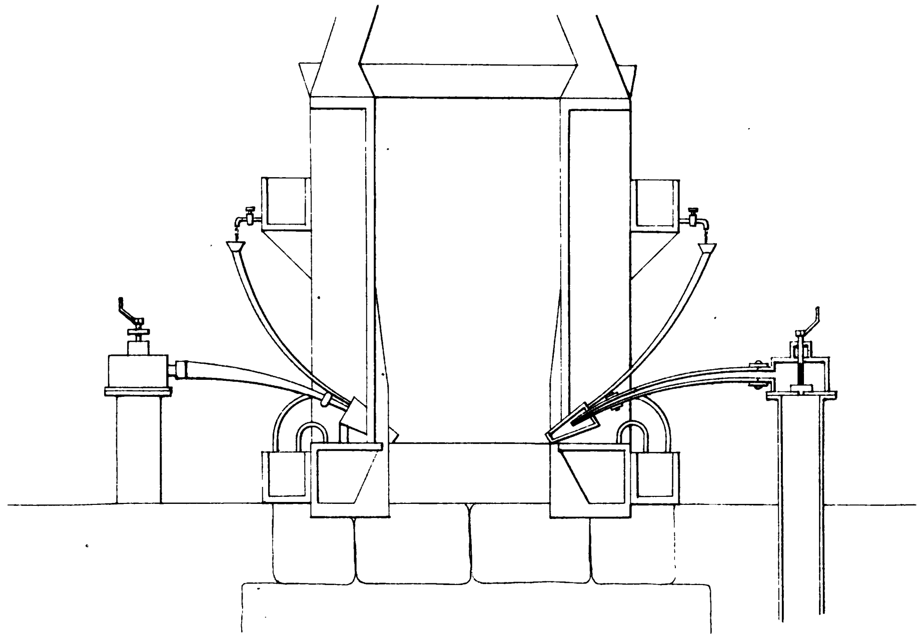
INDEX.

THE END.

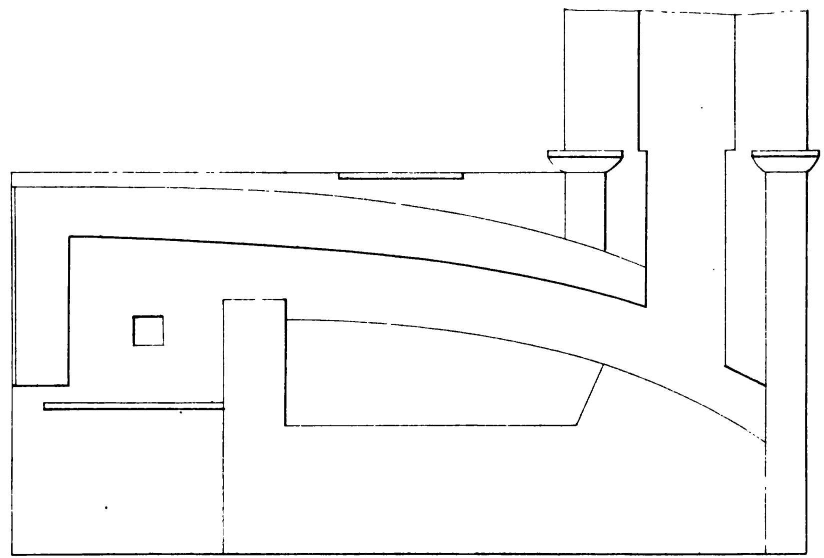
BLAST FURNACE.



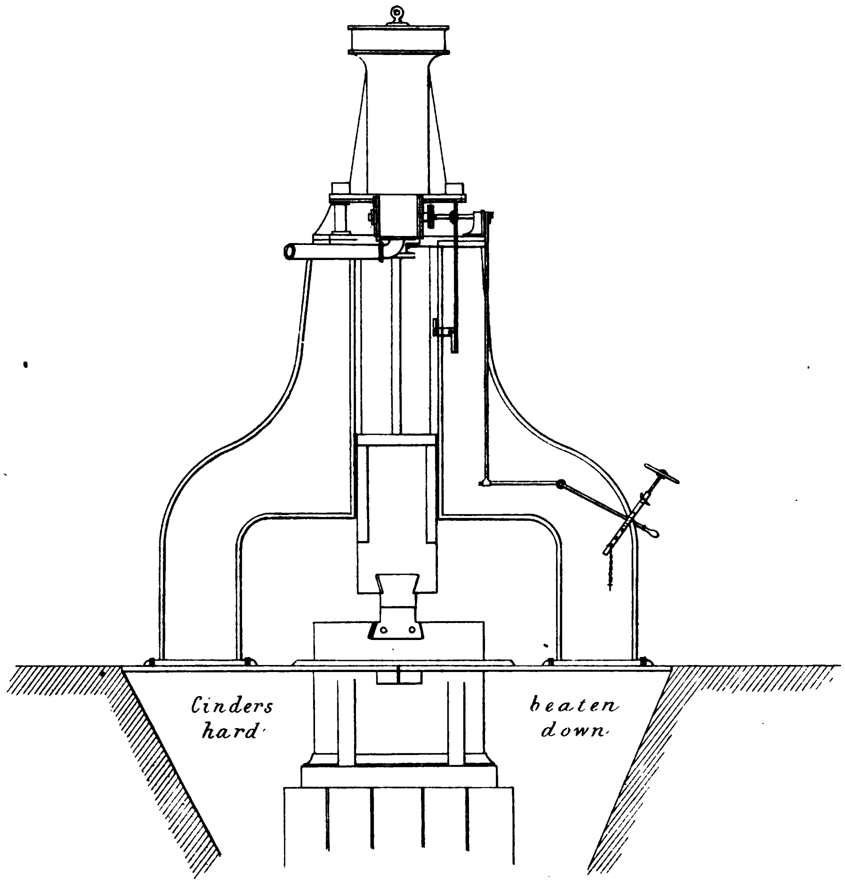
REFINING FURNACE.



REVERBERATORY · FURNACE



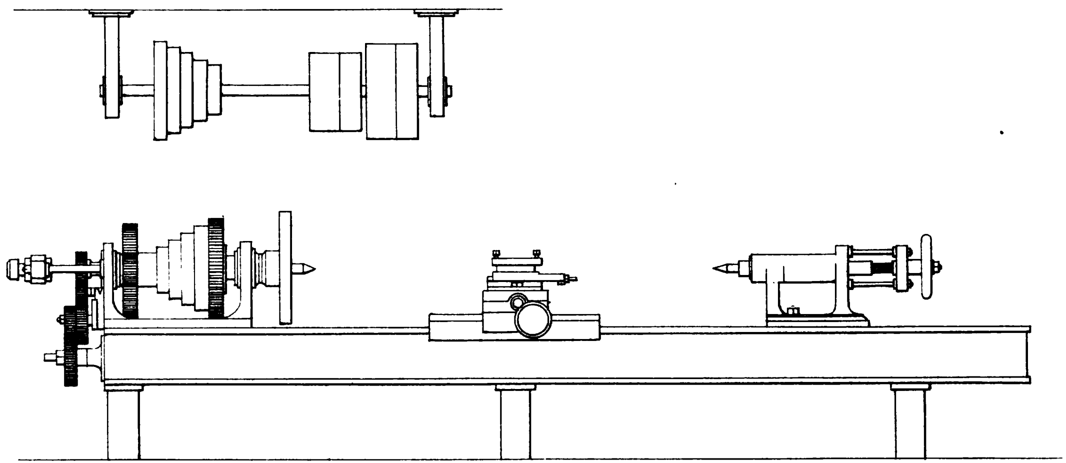
W Francis



Scale 3/16 of an Inch to a foot

Atchley & Co. 106, Great Russell Street, London
Published. January 1863.

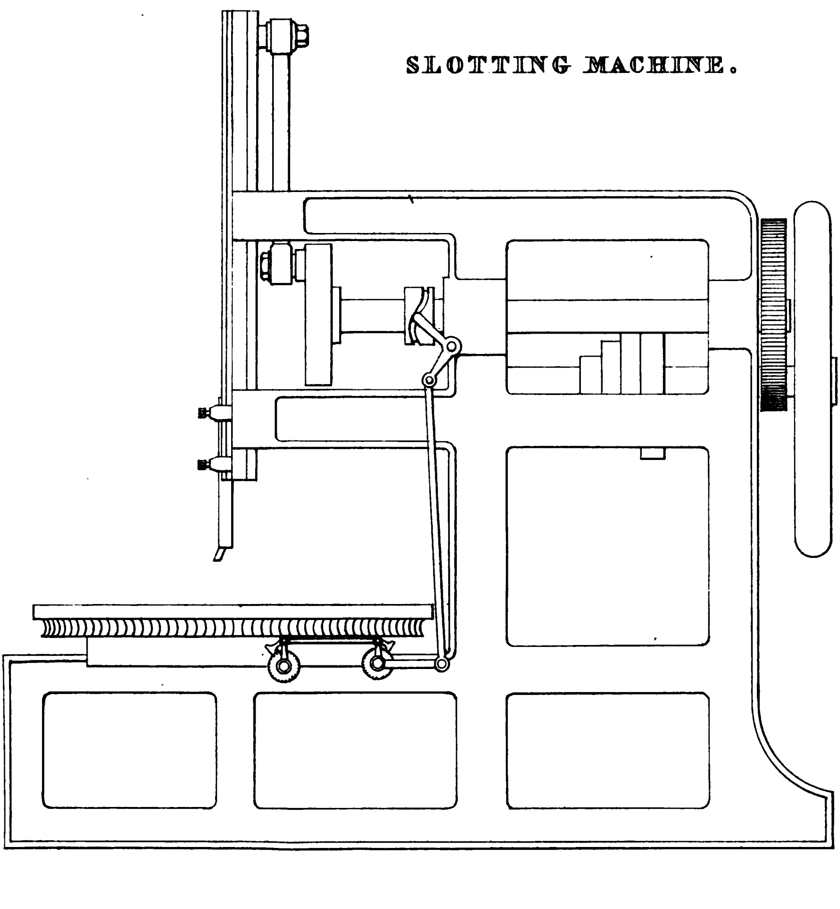
SLIDE & SCREW CUTTING LATHE



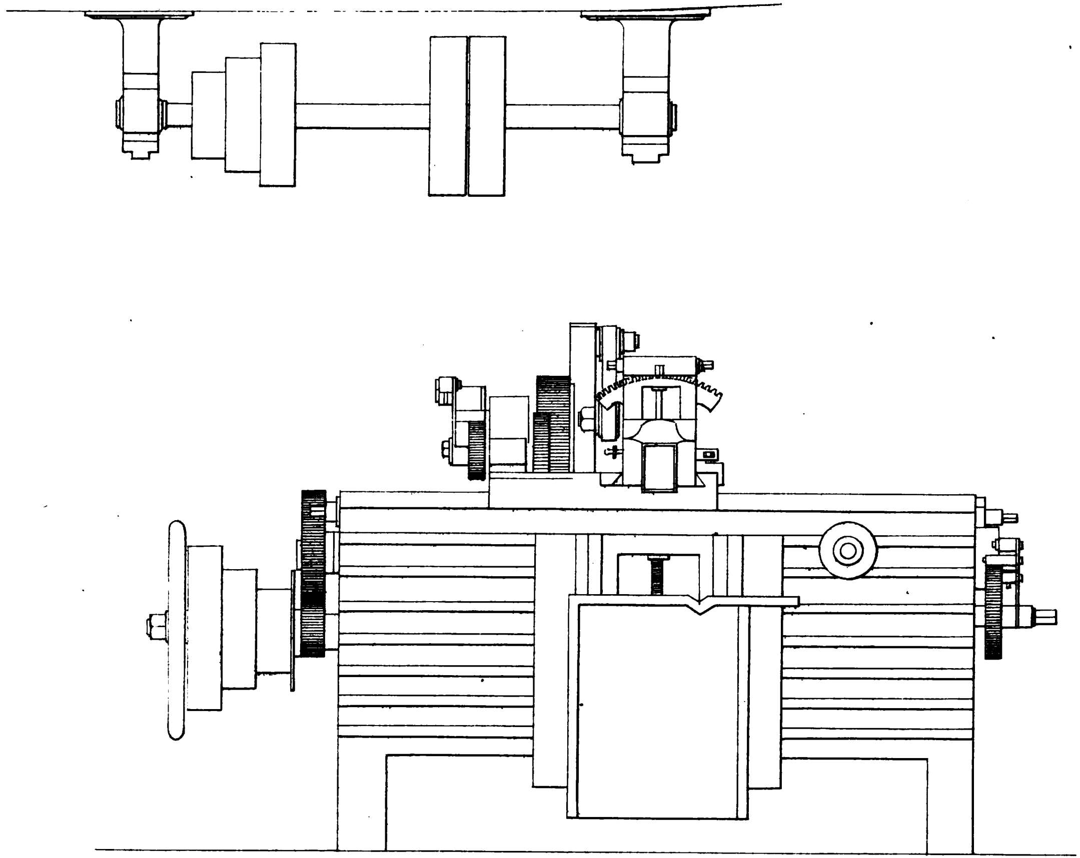
Scale 5/16 Inch = 1 Foot.

W Francis. lith:

SLOTTING MACHINE.



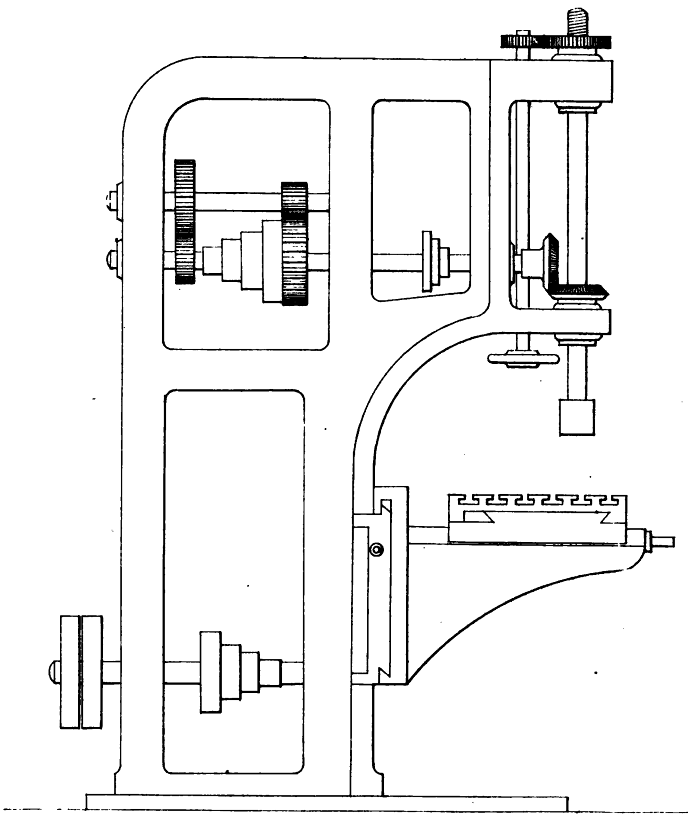
W. Fraz



Scale 2/3 In: — a foot

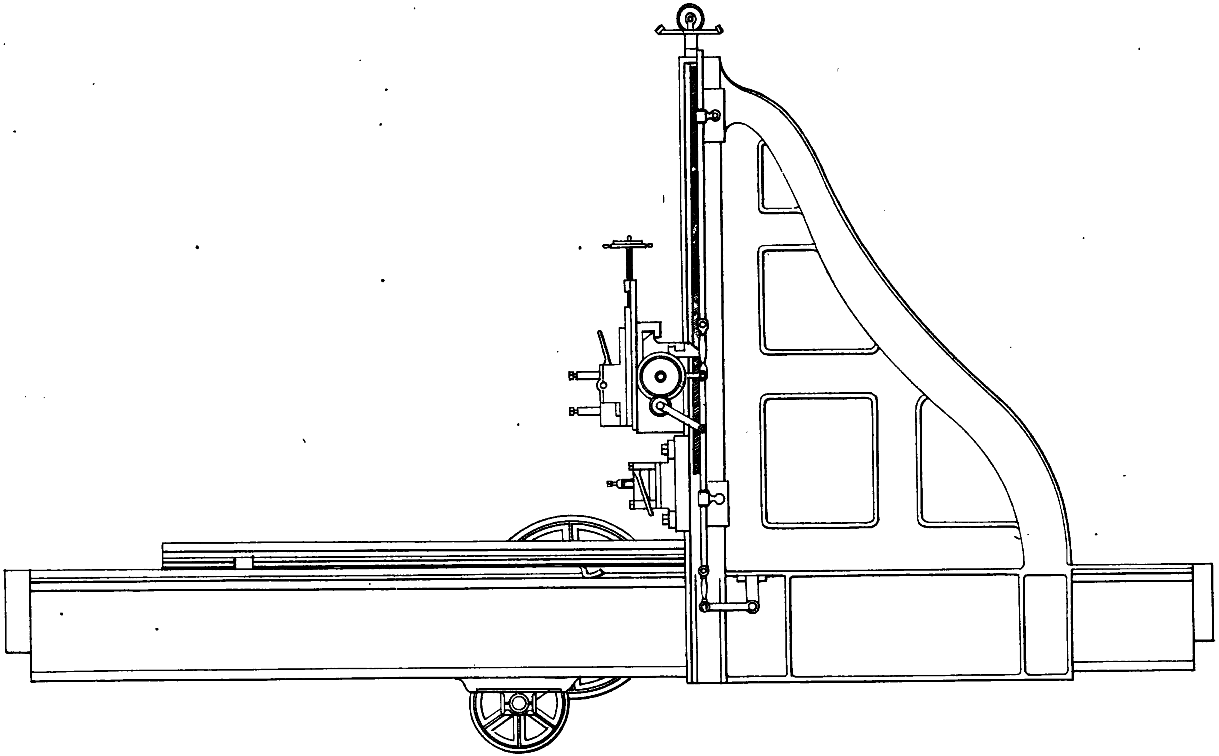
W. Francis. lith:

DRILLING MACHINE.



Scale ½ an Inch to a foot

W. Francis lith.



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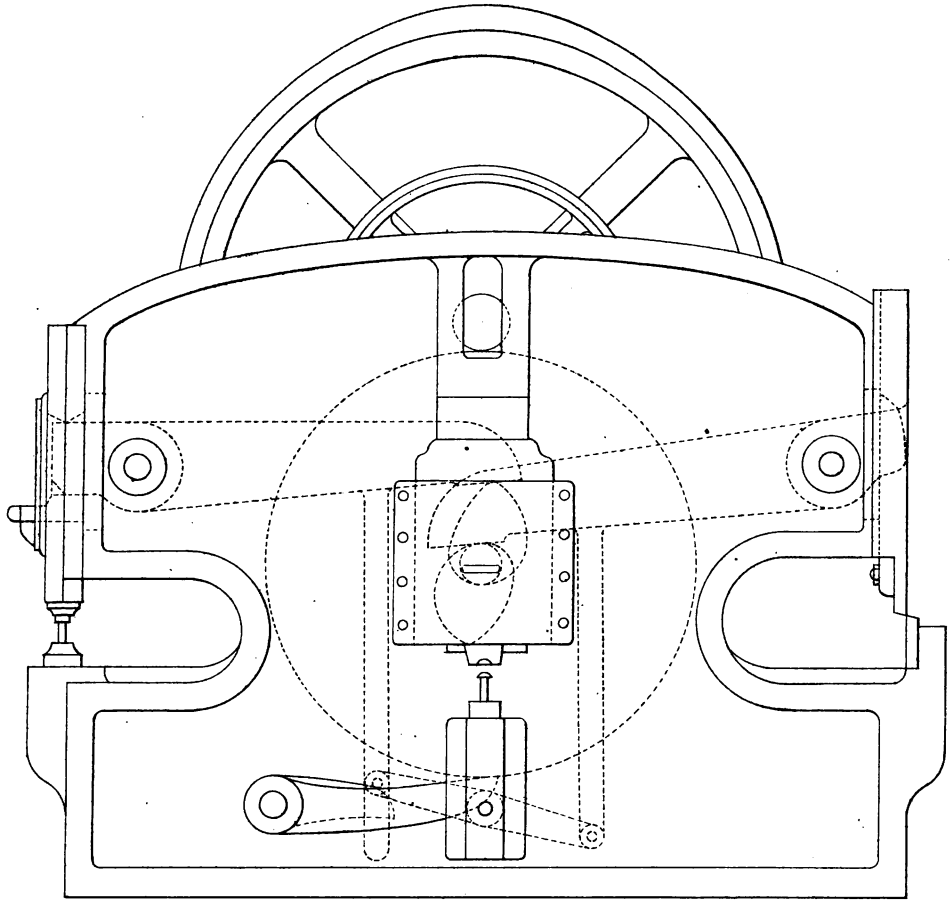
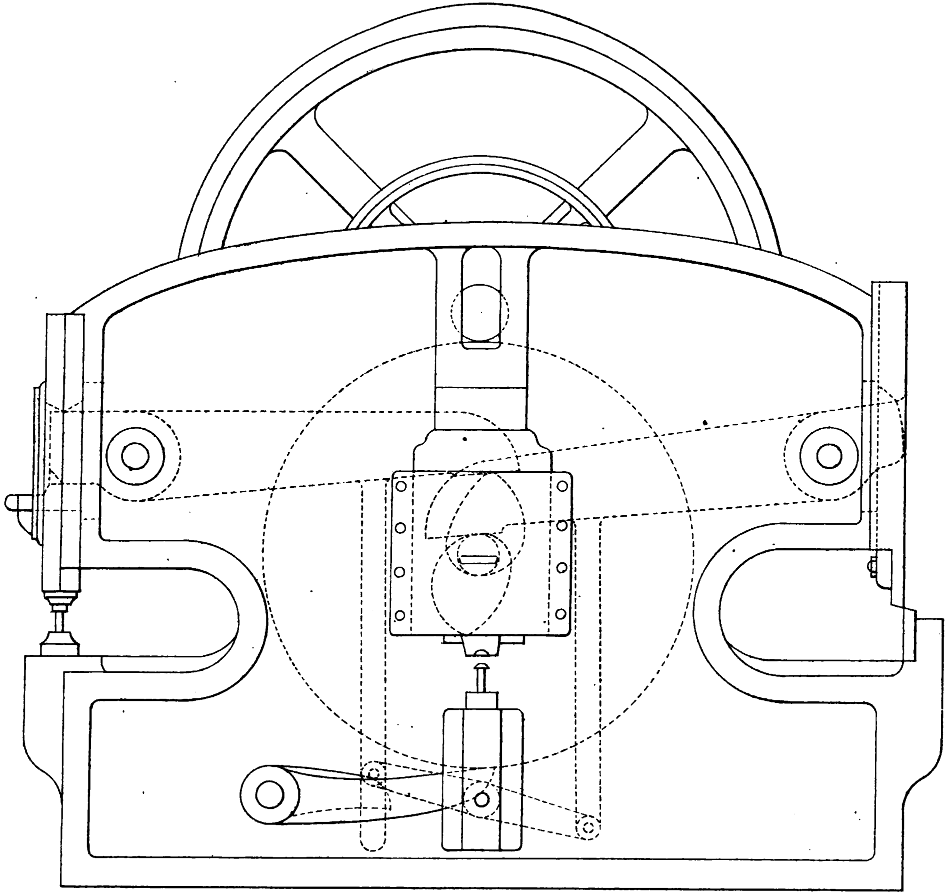


Scale 5/8" — a foot

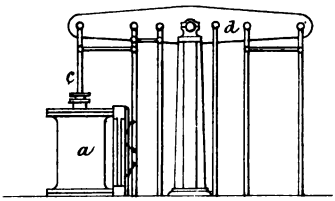
PUNCHING, SHEARING & RIVETTING MACHINE.



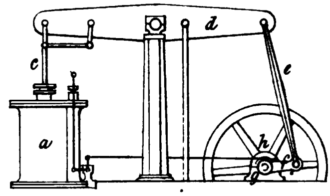
Scale 5/8" = a foot.

GENERAL ARRANGEMENT OF STEAM ENGINES

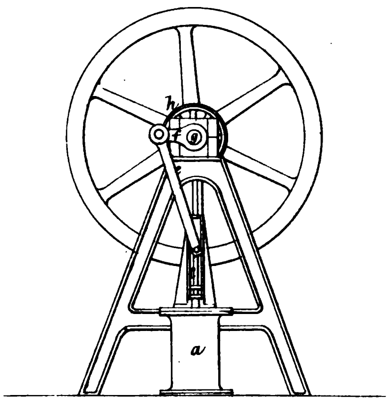
C. PUMPING ENGINE



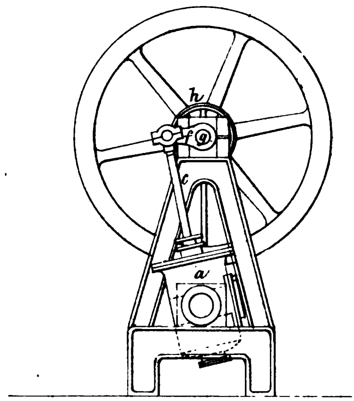
BEAM ENGINE



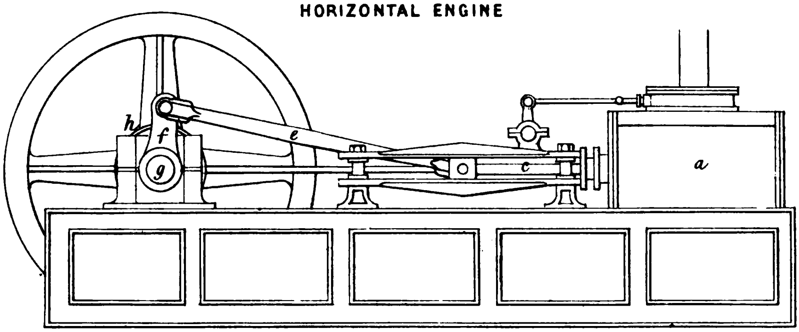
VERTICAL ENGINE



OSCILLATING ENGINE



HORIZONTAL ENGINE



VARIOUS FORMS OF GOVERNORS.

FIG. 1

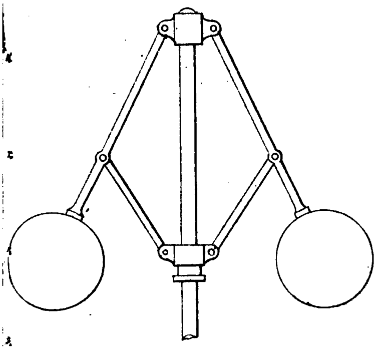


FIG. 2

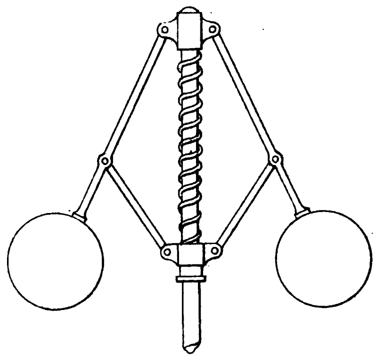


FIG. 4.

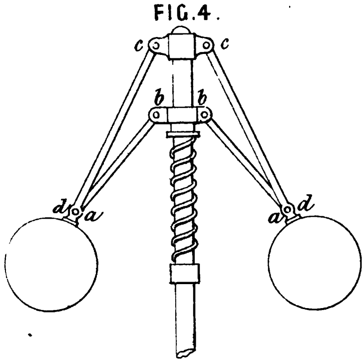


FIG. 3.

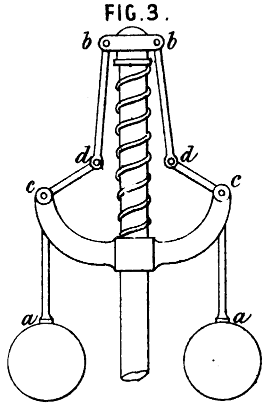


FIG. 5.

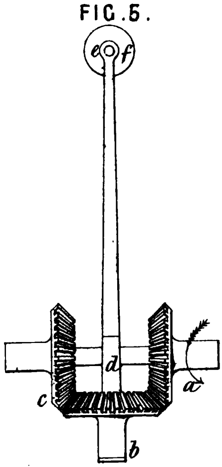
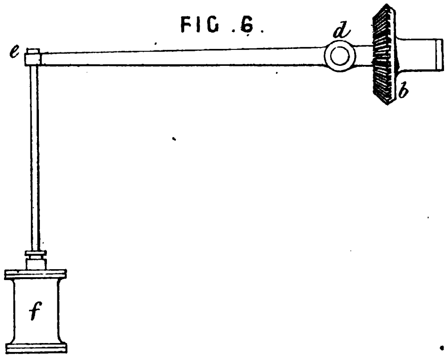
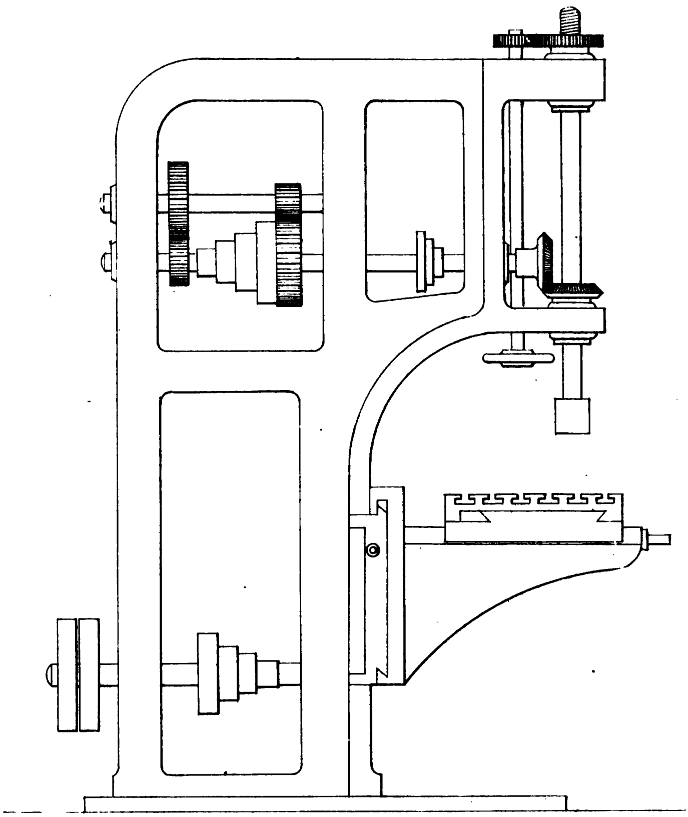


FIG. 6.



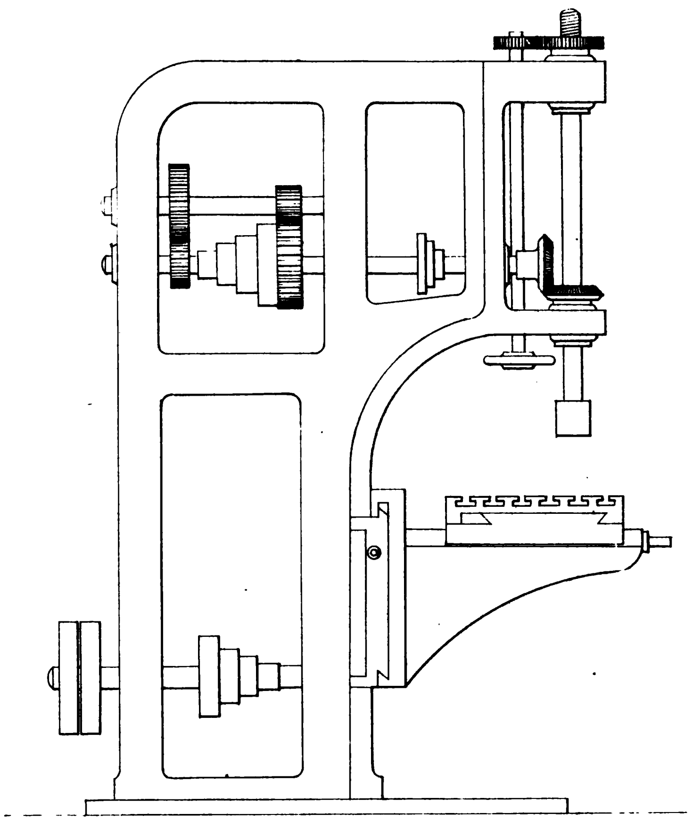
DRILLING MACHINE.



Scale ½ an Inch to a foot

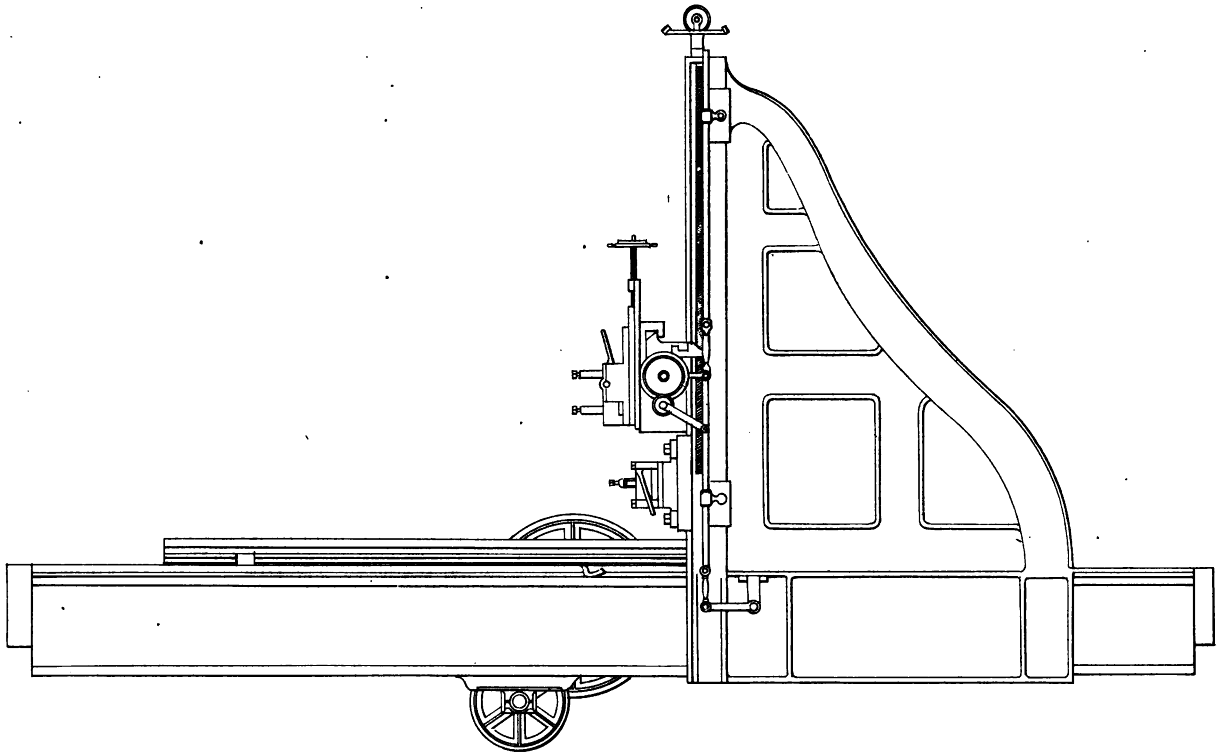
W. Francis lith.

DRILLING MACHINE.



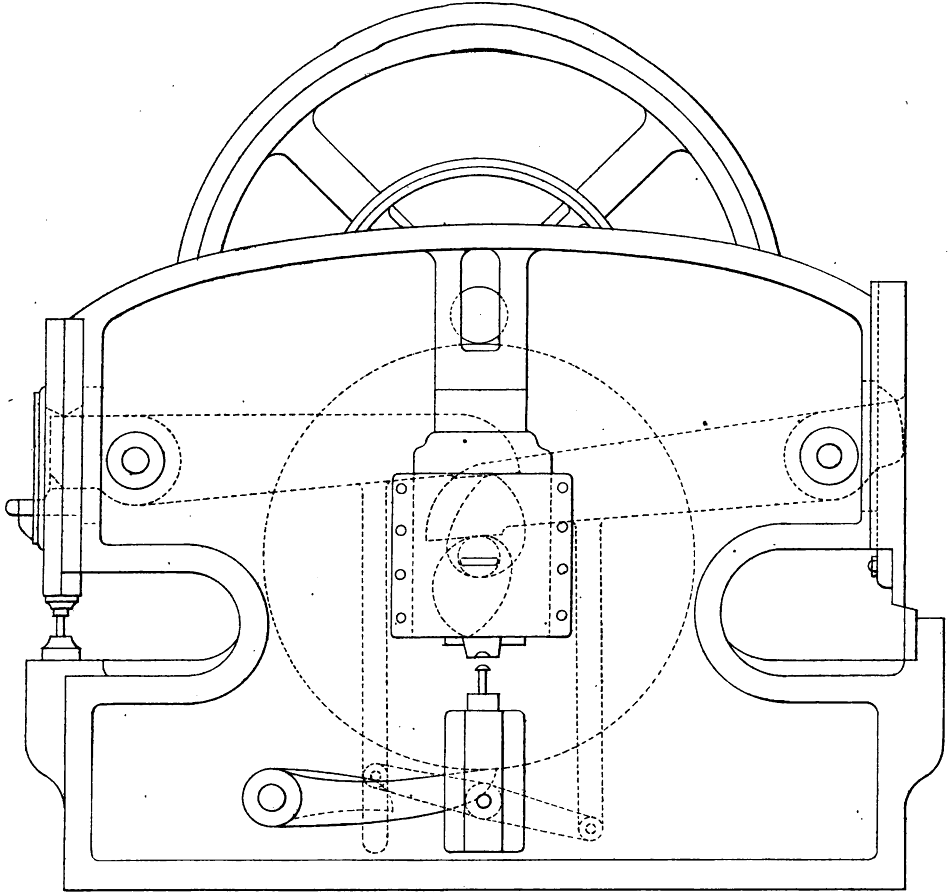
Scale ½ an Inch to a foot

W. Francis lith.



Scale ⅓ Inch — a foot

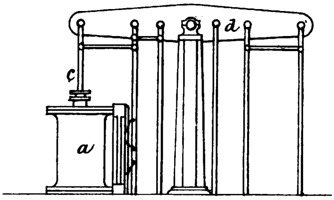
PUNCHING, SHEARING & RIVETTING MACHINE.



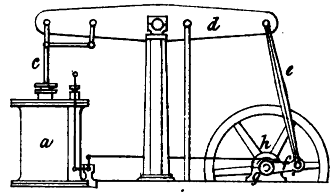
Scale $5/8''$ — a foot

GENERAL ARRANGEMENT OF STEAM ENGINES

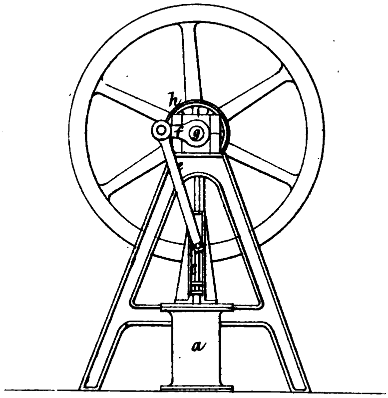
C. PUMPING ENGINE



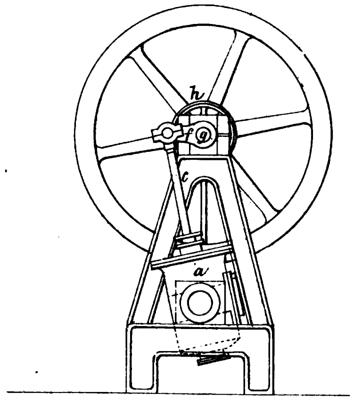
BEAM ENGINE



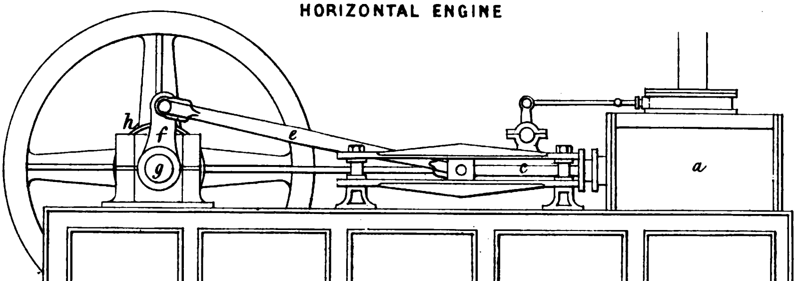
VERTICAL ENGINE.



OSCILLATING ENGINE



HORIZONTAL ENGINE



VARIOUS FORMS OF GOVERNORS.

FIG. 1

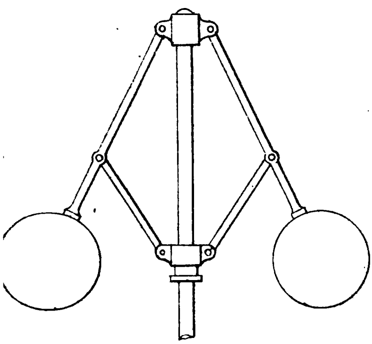


FIG. 2

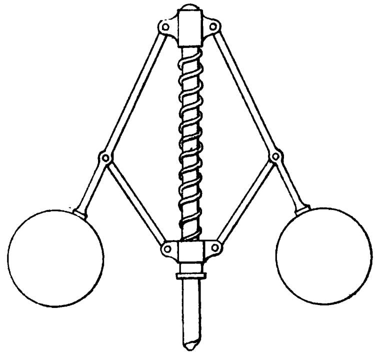


FIG. 4.

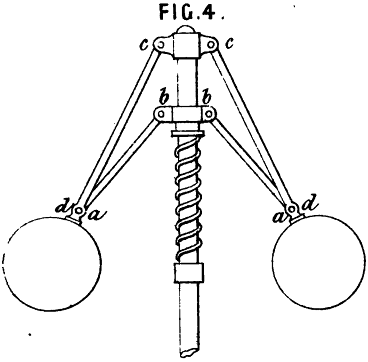


FIG. 3.

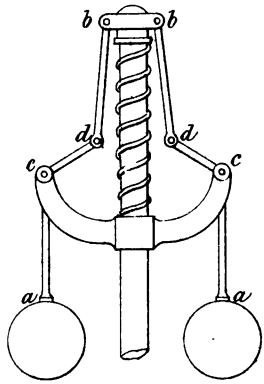


FIG. 5.

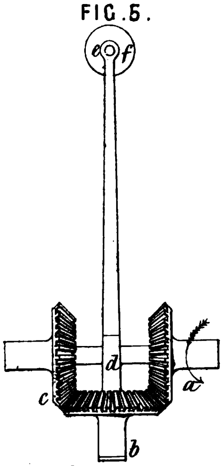
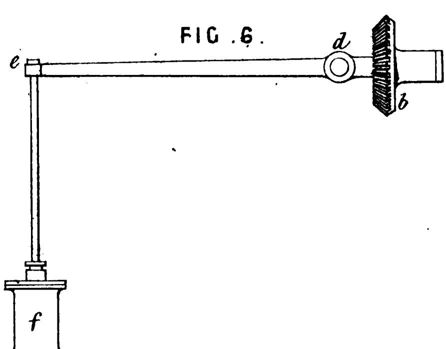


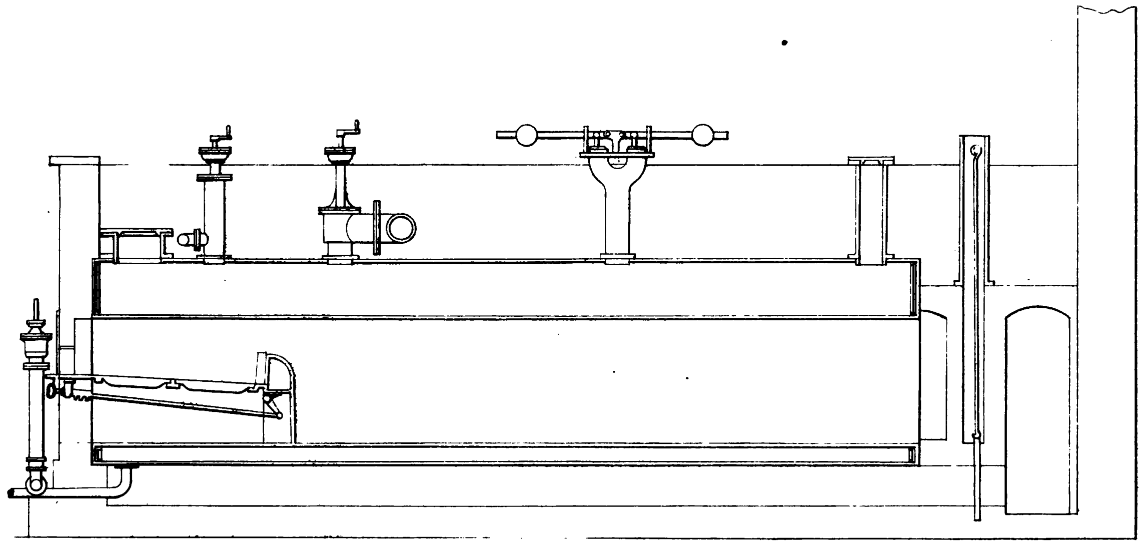
FIG. 6.



CORNISH BOILER.

ERECTED AT THE SCARBORO' WATER WORKS.

THOMAS WICKSTEED ESQ. M.I.C.E. ENGINEER.

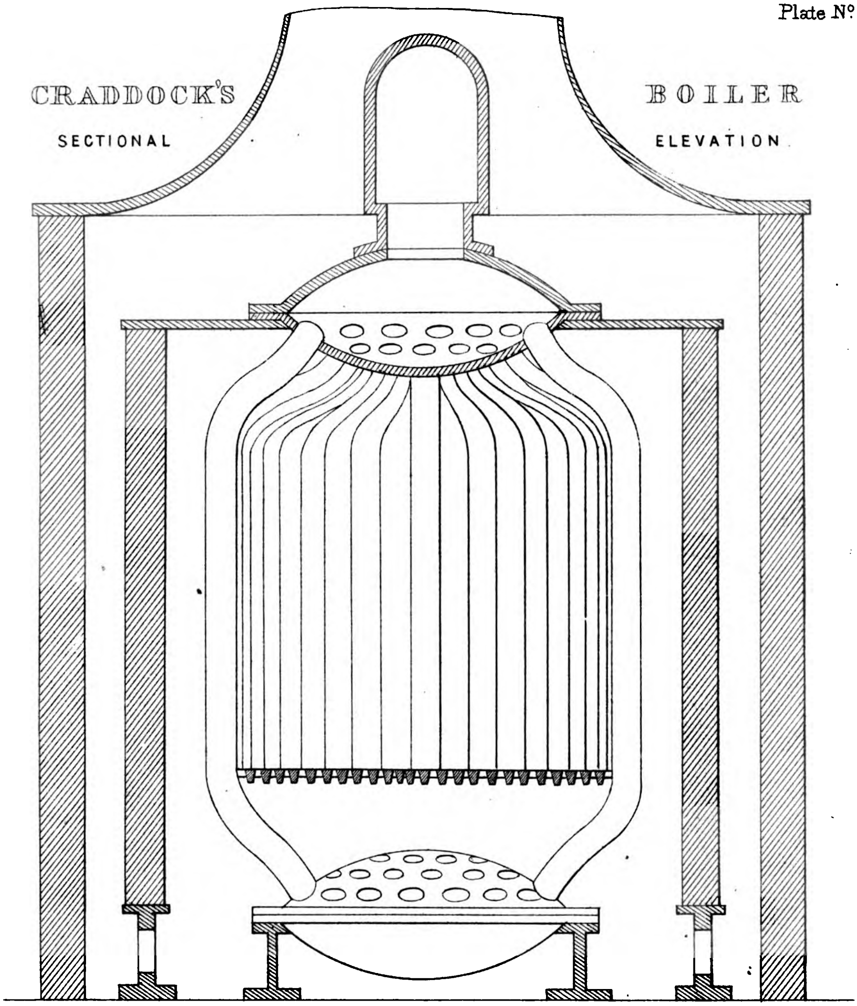


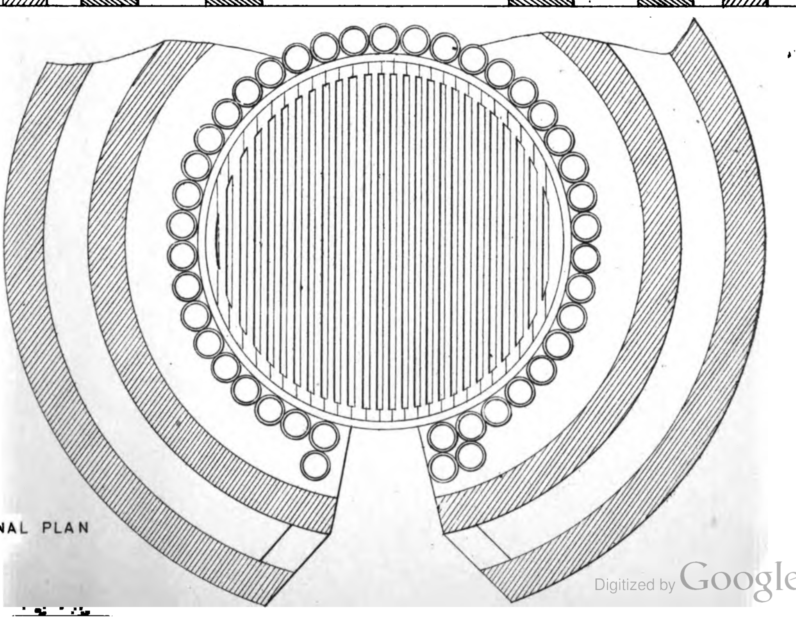
Scale ¼ Inch-1 Foot

Atchley & C° Great Russell Street W.C
Published January 1863.

CRADDOCK'S BOILER

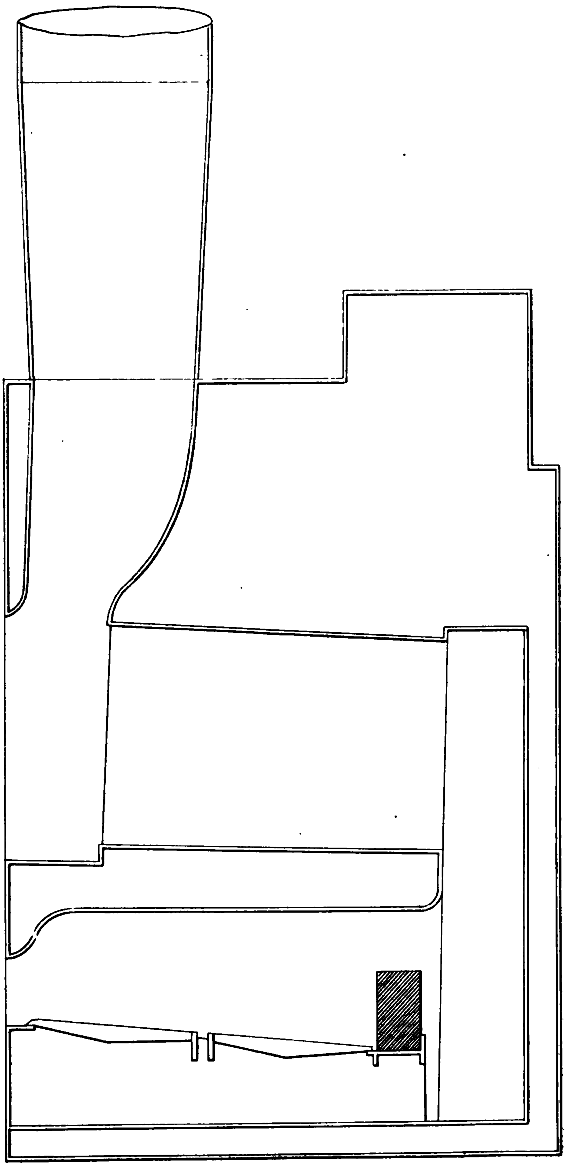
SECTIONAL ELEVATION



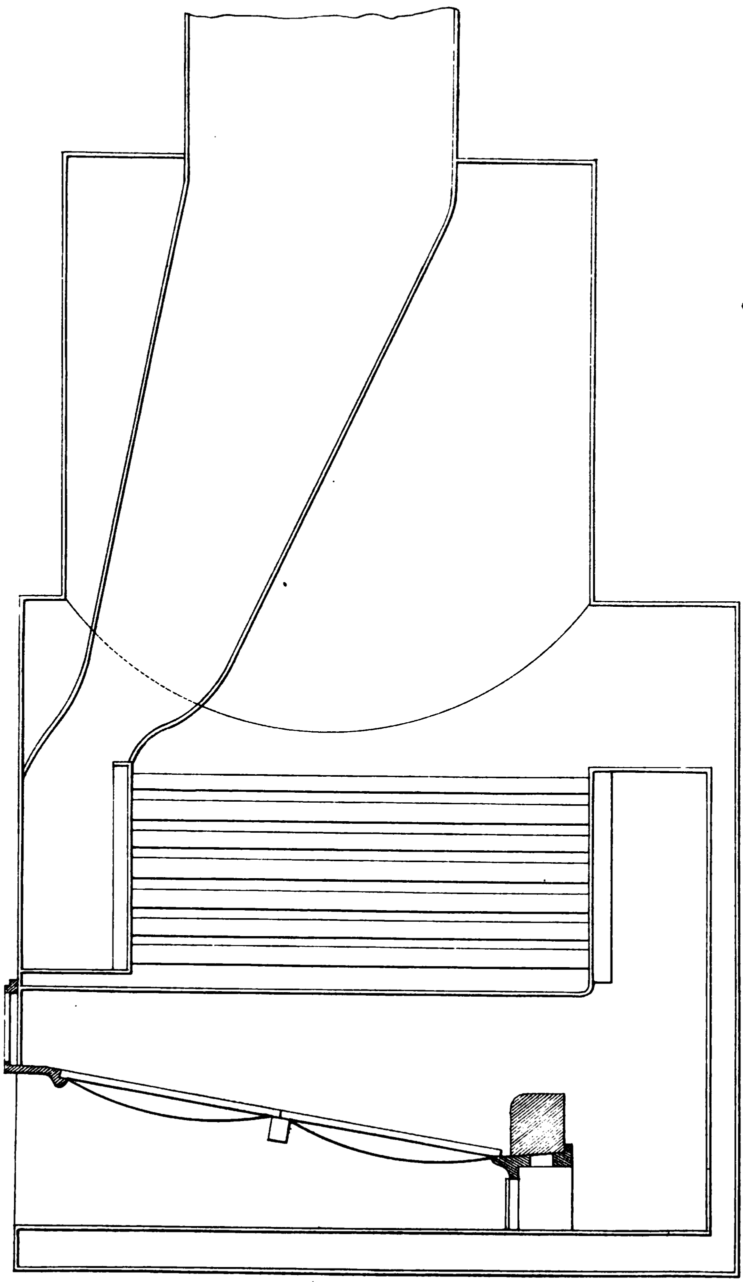


SECTIONAL PLAN

MARINE FLUE BOILER



MARINE TUBULAR BOILER.



GUMPEL'S PROPELLER.

FIG. 1.

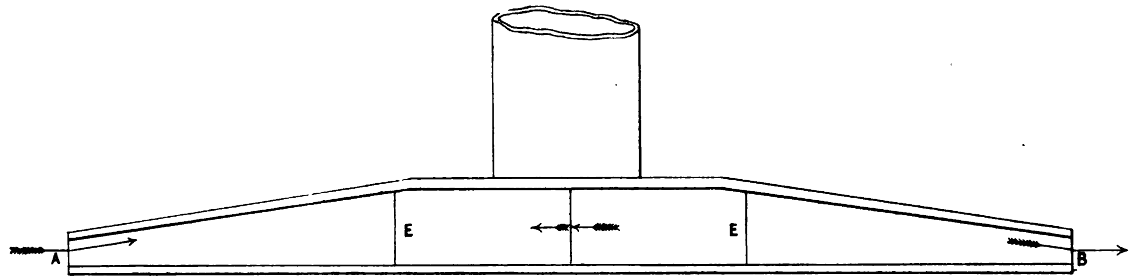
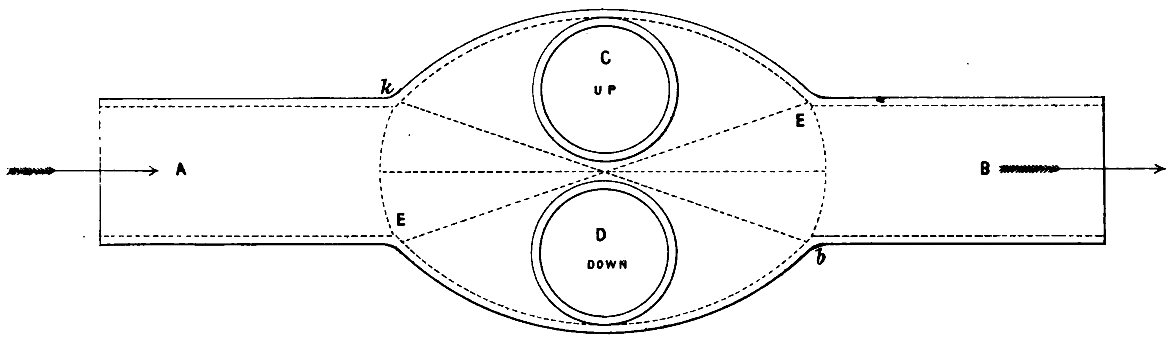


FIG. 2.

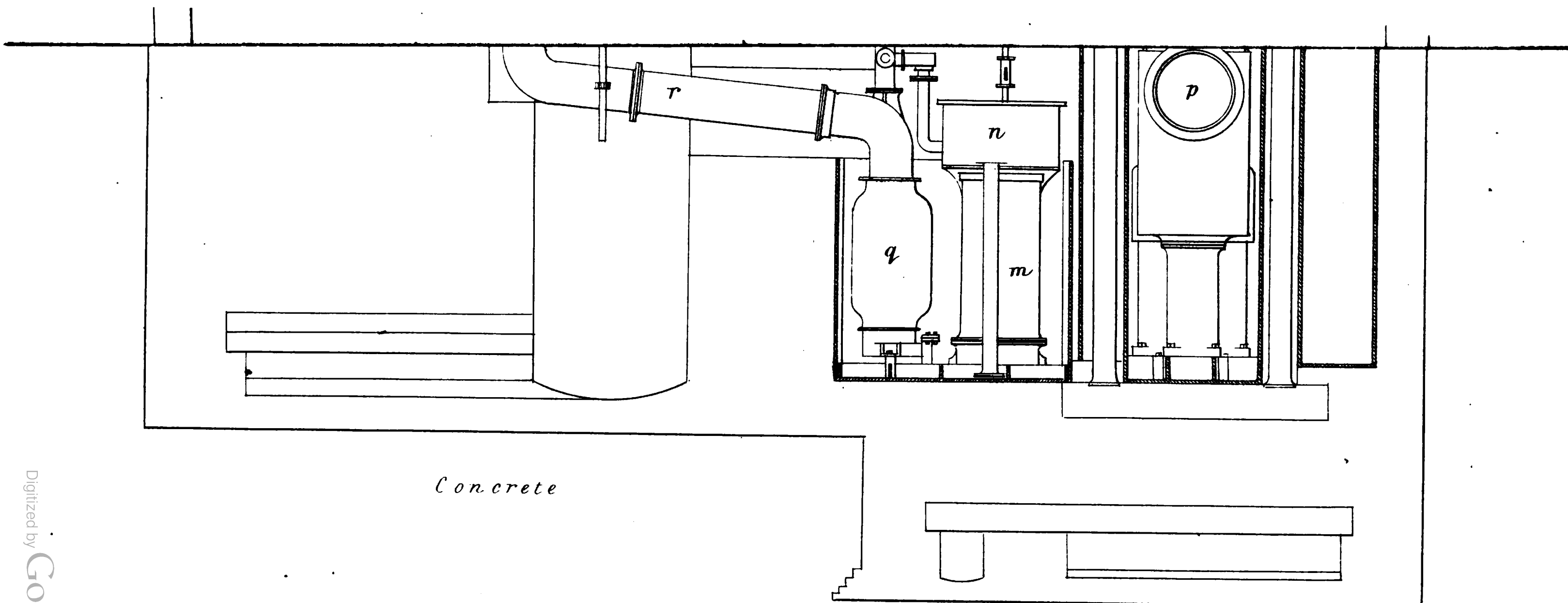


W. Francis

Plate No. 18

ELEVATION OF GRAND JUNCTION WATERWORKS ENGINE. 1845.

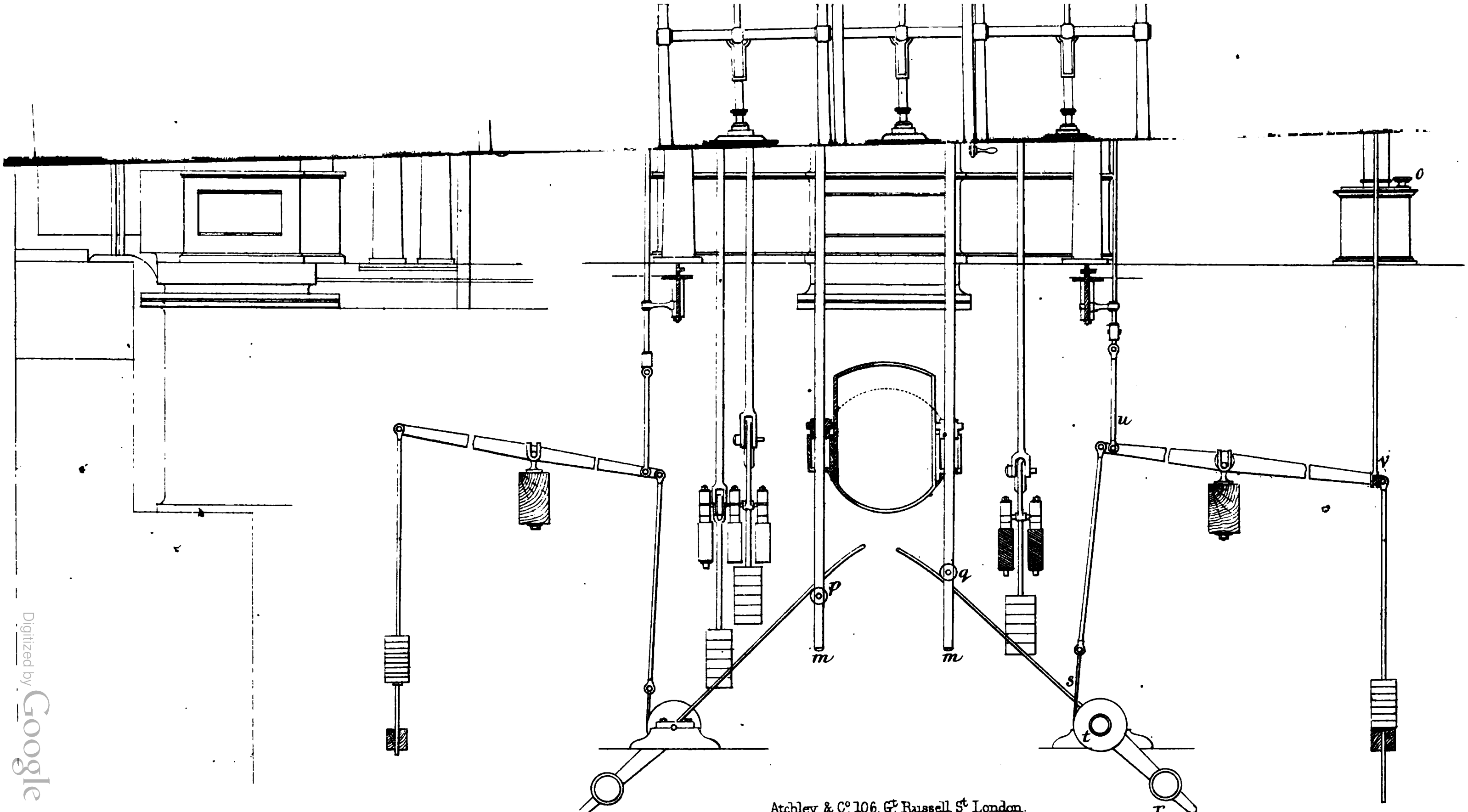
THOMAS WICKSTEED ESQ. ENGINEER.



Scale 1/8 Inch to 1 Foot.

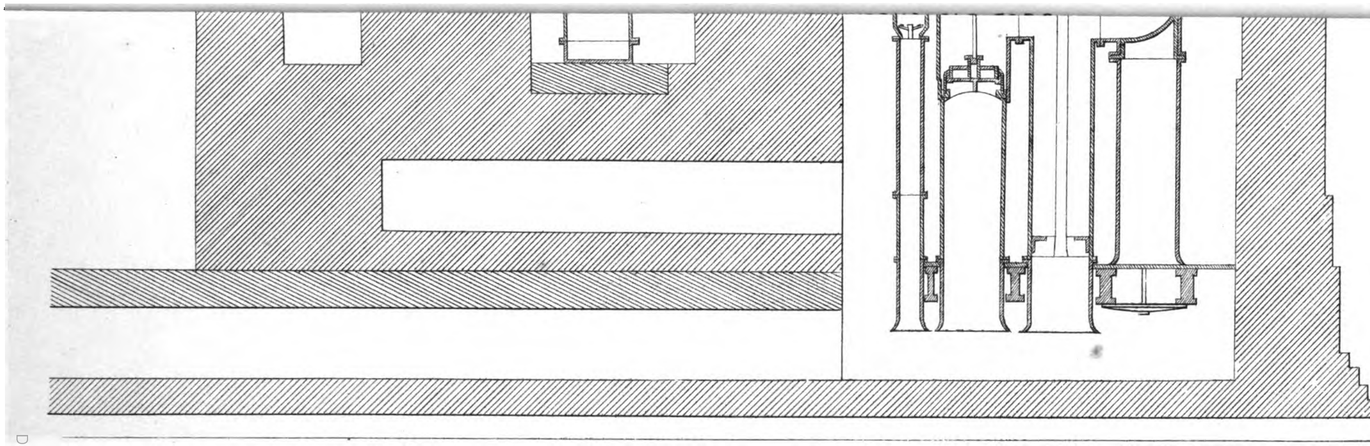
W Francis

Atchley & Co. 106 Great Russell St. London.
Published. January 1863



Atchley & Co. 106, Gt. Russell St. London.
Published Jany. 1863.

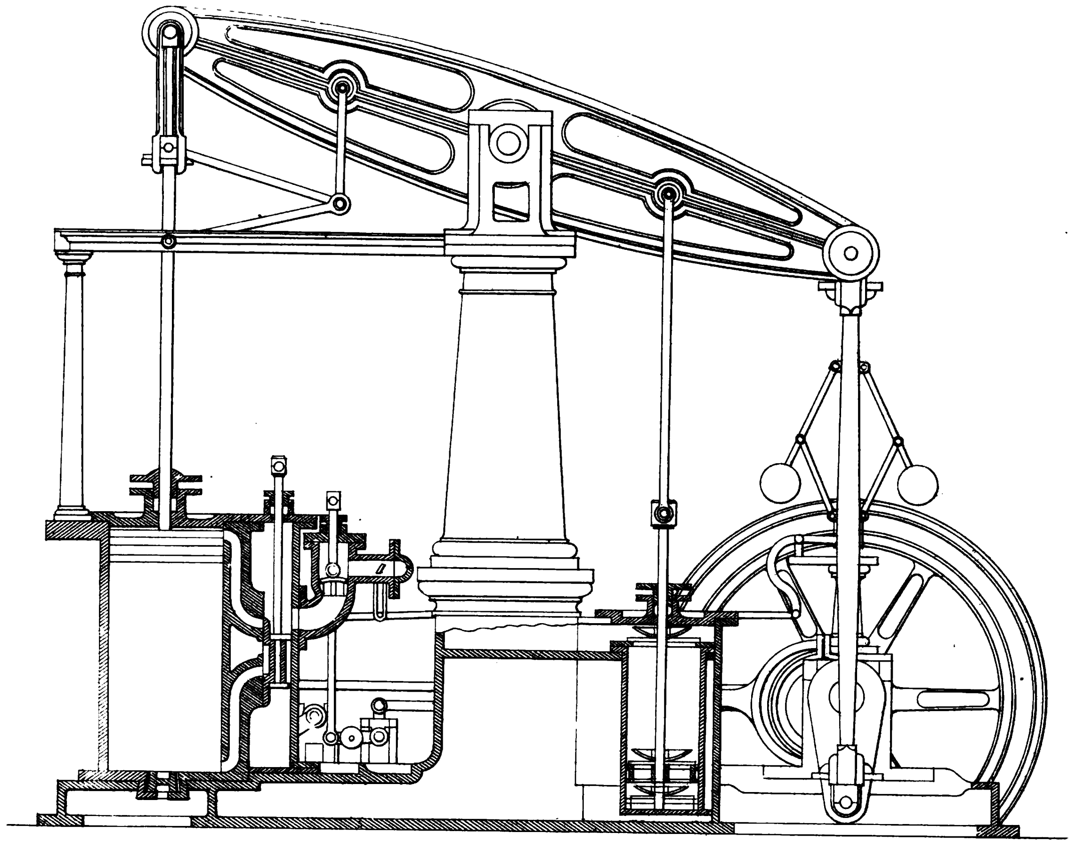
LONGITUDINAL SECTION OF THE BOULTON WATT ENGINE,



Scale 8 Feet to an Inch

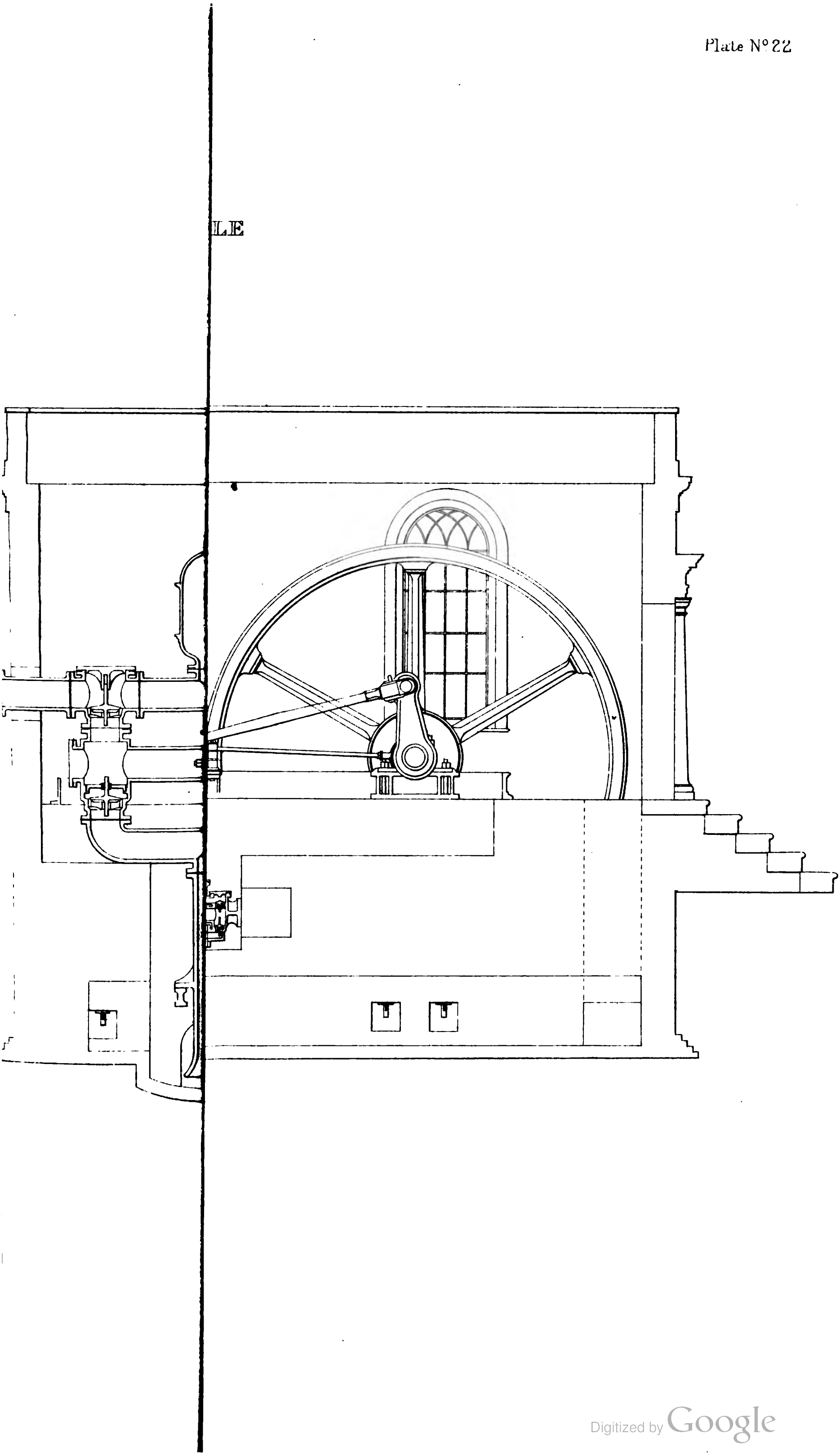
Atchley & C°. 106. Great Russell Street. London
Published. January 1863.

W Francis lith

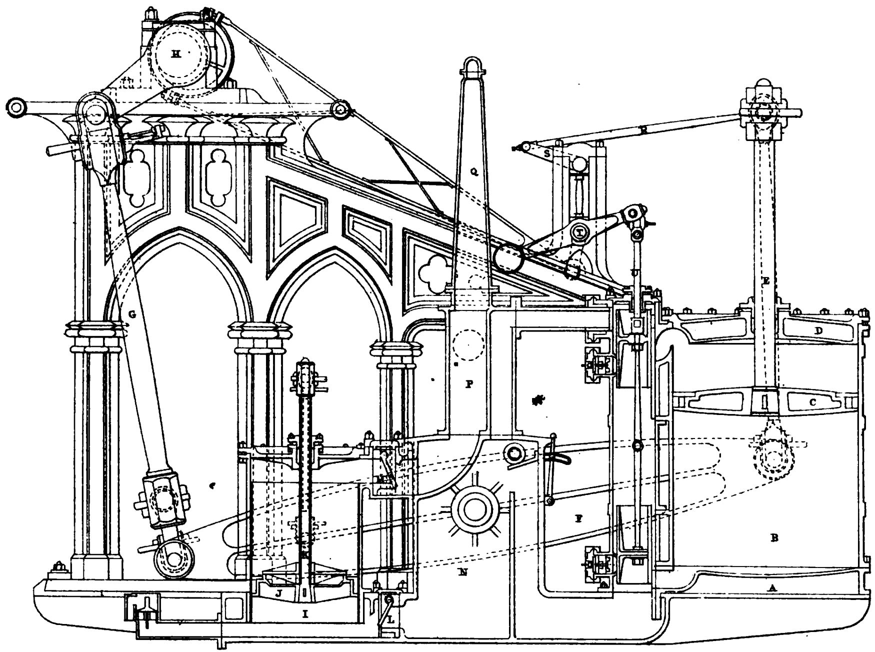


Scale 3/8 Inch — 1 Foot

W. Francis lith:


LE

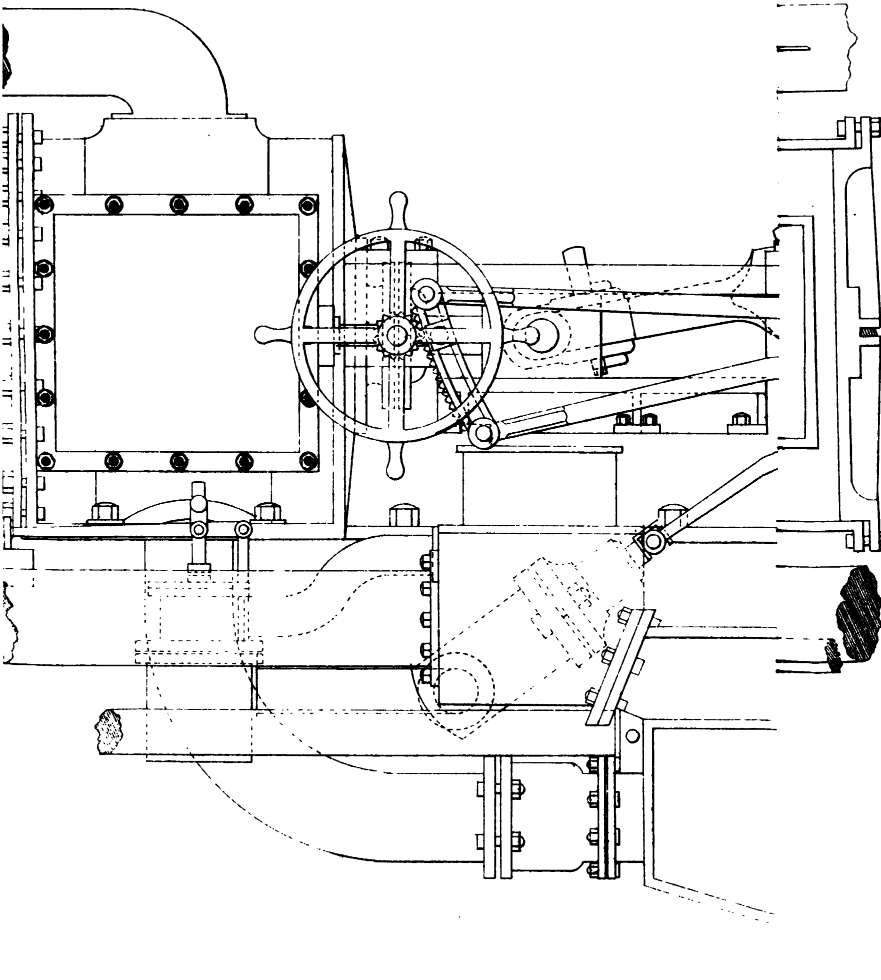
SIDE LEVER MARINE ENGINE



Atchley Cº 106, Great Russell Street, London.
Published. January 1863.

ELEVATION OF A

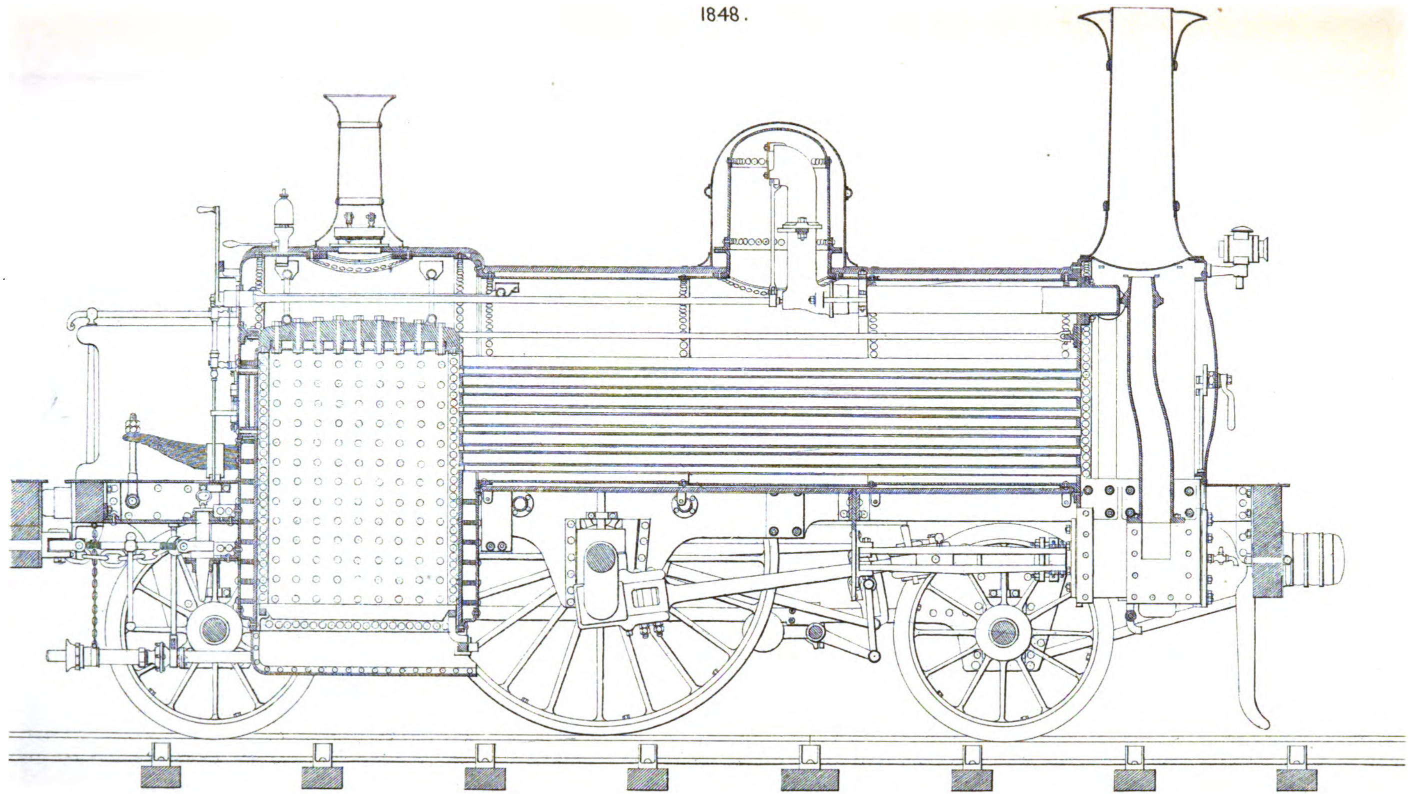
On the di.



FOR THE

YORK NEWCASTLE & BERWICK RAILWAY.

1848.



SCALE OF 0 1 2 3 4 5 6 7 8 9 10 11 FEET.

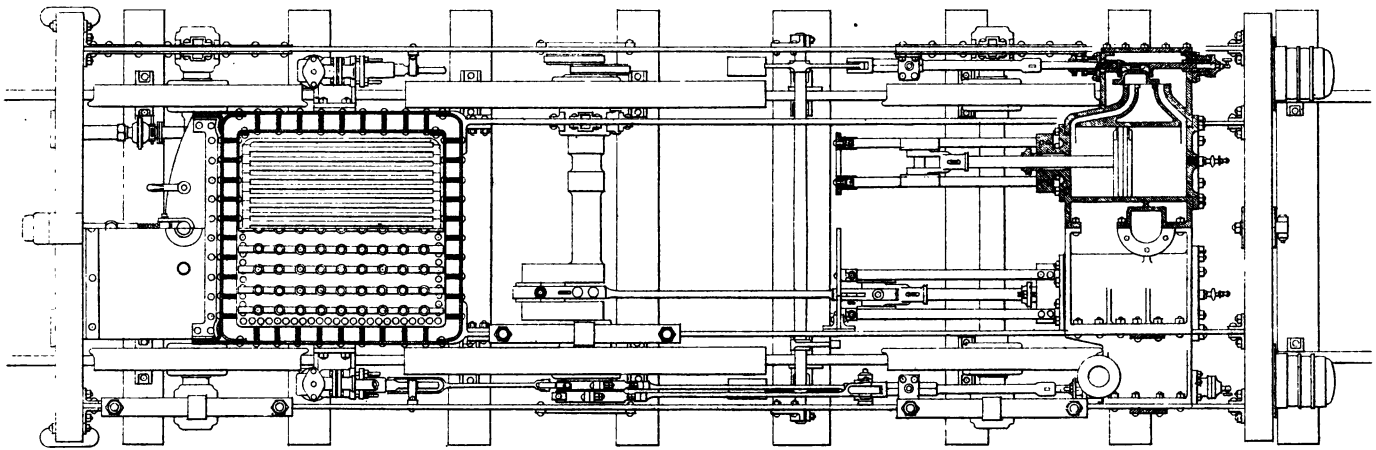
Atchley Cº 106, Great Russell Street, London.
Published January 1863

MANUFACTURED BY MESSRS ROBT STEPHENSON & Co

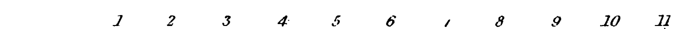
FOR THE

YORK NEWCASTLE & BERWICK RAILWAY.

1849.



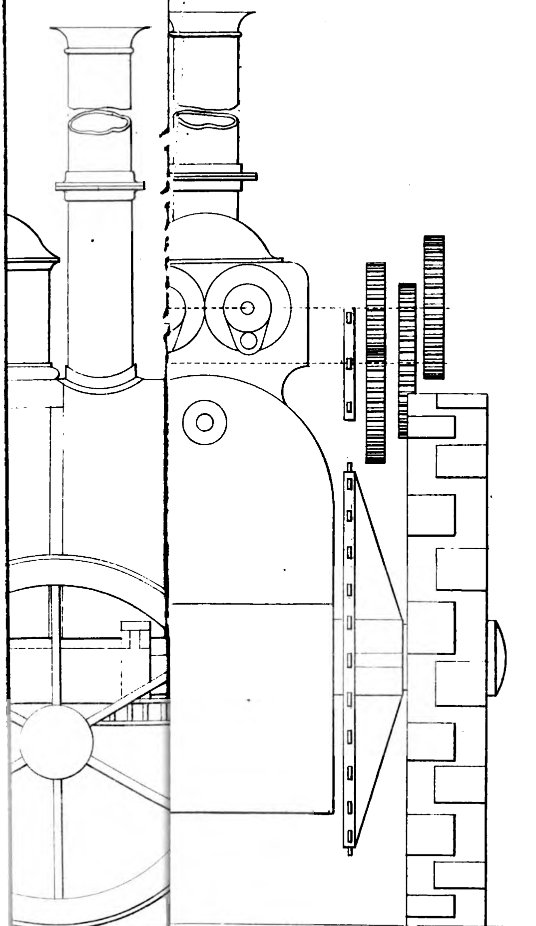
Scale of Feet.



Atchley Co 106, Great Russell Street, London.
Published. January 1863.

Plate No. 27

.GRICULT

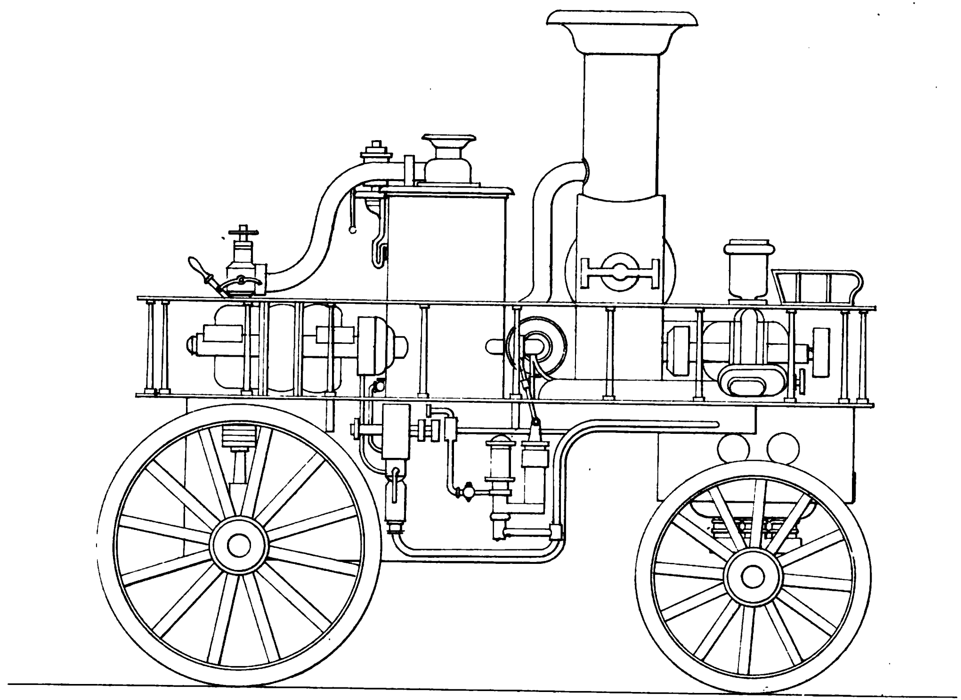


Inch – 1 Foot

Grea Russell St
shed January 18

W Francis

SILSBY, MYNDERSE & C$^{o.s}$ STEAM FIRE ENGINE.



W. Francis. lith.

2666